

**NASA CONTRACTOR
REPORT**



NASA CR-2486

NASA CR-2486

**PARAMETRIC STUDY OF STOL
SHORT-HAUL TRANSPORT ENGINE CYCLES
AND OPERATIONAL TECHNIQUES
TO MINIMIZE COMMUNITY NOISE IMPACT**

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • NOVEMBER 1974

1. Report No. NASA CR - 2486		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle PARAMETRIC STUDY OF STOL SHORT-HAUL TRANSPORT ENGINE CYCLES AND OPERATIONAL TECHNIQUES TO MINIMIZE COMMUNITY NOISE IMPACT				5. Report Date November 1974	
				6. Performing Organization Code	
7. Author(s)				8. Performing Organization Report No.	
9. Performing Organization Name and Address Douglas Aircraft Company Long Beach, California				10. Work Unit No.	
				11. Contract or Grant No. NAS 2-6994	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546				13. Type of Report and Period Covered Contractor Report/Summary	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract <p>The main goal of this study was to investigate the effect of aircraft operational techniques in the terminal area on community noise impact of future short-haul aircraft. These operational techniques affected both the takeoff and landing flight profiles. The parameters that varied at takeoff were flap retraction altitude, flap retraction rate, thrust cutback altitude, amount of thrust cutback, and amount of turning. During landing the parameters varied were glide slope angle, change in slope angle (two segment approach), and flap extension rate. One mechanical-flap (MF) aircraft and one externally-blown-flap (EBF) aircraft were used to study the noise impact at four U. S. airports: Hanscom Field (Boston); Washington National; Midway (Chicago); and Orange County (California). With the exception of Washington National (DCA), the study showed that a reduction of approximately 40 percent in the number of people highly annoyed (as defined in the study) can be obtained by using these operational techniques. At DCA the number of people highly annoyed using the standard procedure was quite low, but it is significant that the minimum-impact case for Runway 36 reduced the number of people highly annoyed to zero by using a power cutback and a turning departure path. The evaluation procedures and methodology developed in this study represents an advance in acoustical state-of-the-art and should provide an effective and useful tool for determining aircraft noise impact upon the airport community.</p>					
17. Key Words (Suggested by Author(s)) STOL Quiet Turbo-fan Aircraft Commercial Short-haul Transports Design Studies				18. Distribution Statement UNCLASSIFIED-UNLIMITED CAT. 02	
19. Security Classif. (of this report) UNCLASSIFIED		20. Security Classif. (of this page) UNCLASSIFIED		21. No. of Pages 87	
				22. Price* \$4.00	

FOREWORD

This report covers a study performed for NASA Ames, "Parametric Study of STOL Short-Haul Transport Engine Cycles and Operational Techniques to Minimize Community Noise Impact", under Contract NAS 2-6994, Mod. No. 3.

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The ten-month study, initiated in July 1973, was divided into several phases; i.e., engine cycle studies, propulsion system and acoustics trade studies, aircraft sizing and operational techniques, and community noise impact analyses.

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SYMBOLS & ABBREVIATIONS

A_f	Fan frontal area
AR	Aspect ratio
ARP	Airport reference point
ASKM	Available seat kilometer
ASSM	Available seat statute mile
ATC	Air traffic control
BED	Hanscom Field (Boston)
BPR	Bypass ratio
B-727	Boeing Model 727
C	Centigrade; cost
C_d	Discharge coefficient
C_D	Drag coefficient
C_{D_0}	Zero lift parasitic drag coefficient - zero lift parasitic drag/ qS_w
CFM	Cubic feet per minute
C_L	Lift coefficient - lift/ qS_w
C.S.D.	Constant speed drive
CTOL	Conventional takeoff and landing
C_μ	Gross thrust coefficient = gross thrust/ qS_w
C_v	Nozzle velocity coefficient
dB	Decibel
D	Drag; diameter
DCA	Washington National Airport
DOC	Direct operating cost
EGA	Extra ground attenuation
EPA	Environmental Protection Agency

EBF	Externally-blown-flap
EPNL	Effective perceived noise level
EPNdB	Effective perceived noise level in decibels
F	Thrust force; Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Air Regulations
FL	Field length
FPR	Fan pressure ratio
fps	Feet per second
ft	Feet
G.A.	General aviation
H	Height of duct flow channel
h_{CRUISE}	Cruise altitude
HP	Horsepower
H.P.	High pressure
IAS	Indicated air speed
in	Inch
K	Kelvin
KE	Kinetic energy
KIAS	Indicated airspeed in knots
kg	Kilogram
kW	Kilowatt
L	Length; left
LAX	Los Angeles International Airport
LFL	Landing field length
L.P.	Low pressure
lb	Pound

m	Meter
M	Mach number
MAC	Mean aerodynamic chord
MDW	Midway Airport (Chicago)
MF	Mechanical flap
MIT	Massachusetts Institute of Technology
mps	Meters per second
N	Newton
NASP	FAA National Airport System Plan
OEW	Operators empty weight
P	Pressure
PL	Payload
PLS	Propulsive lift system
PNdB	Perceived noise level in decibels
PNL	Perceived noise level
Psgr	Passengers
q	Free stream dynamic pressure
Q	Torque; quantity (no. of engines)
QCSEE	Quiet Clean STOL Experimental Engine
QRPLS	Quick response powered-lift system
R	Rankine; right
Rwy	Runway
s	Second
SAE	Society of Automotive Engineers
S_w	Wing area
SLS	Sea level static
SNA	Orange County (Calif.) Airport

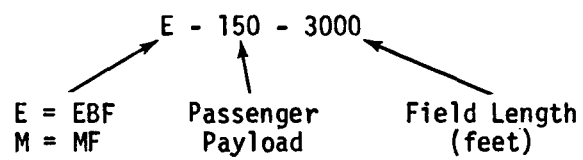
st mi	Statute miles
STOL	Short takeoff and landing
t	Time; thickness
T	Temperature
t/c	Thickness ratio
TOFL	Takeoff field length
TOGW	Takeoff gross weight
T/W	Thrust-to-weight ratio
U.S.A.F.	United States Air Force
U.S.G.S.	United States Geological Survey
V	Velocity
V_R	Relative velocity (primary exhaust velocity - V_0)
V_1	Decision speed
V_2	Speed at end of gear retraction, with critical engine failed
W	Weight; watts
w	Mass flow
W/S	Wing loading
α	Angle of attack
γ	Flight path angle
δ	Pressure relative to sea level standard
δ_F	Flap angle
η_{fan}	Fan efficiency
θ	Aircraft pitch attitude; relative absolute temperature
$\dot{\theta}$	Aircraft pitch rate

Λ	Sweep angle
λ	Taper ratio
μ	Coefficient of friction
ν	Static thrust turning angle
τ	Ratio of gross thrust to takeoff gross thrust
ϕ	Aircraft roll attitude

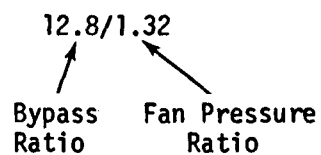
Subscripts

A	Air, airplane trimmed
CR	Cruise
DUCT	Engine fan exhaust duct
PRI	Engine core exhaust duct
T.E.	Trailing edge
T.O.	Takeoff
a	Air
am	Ambient
aver	Average
f	Fuel; fan
g	Gross
max	Maximum
n	Net
o	Free stream, standard sea level
r	Ram
t	Total
ult	Ultimate
0, 2, 4, 28	Engine station position

STOL Aircraft Model Designation



Engine Designation



1.0 SUMMARY

The main goal of this study was to investigate the effect of aircraft operational techniques in the terminal area on community noise impact of future short-haul aircraft. One mechanical-flap (MF) aircraft and one externally-blown-flap (EBF) aircraft were used to study the noise impact at four U.S. airports: Hanscom Field (Boston); Washington National; Midway (Chicago); and Orange County (California). The EBF aircraft was the final design E-150-3000 aircraft developed during the NASA STOL Systems Study, Reference 1.

With the exception of Washington National (DCA), the study showed that a reduction of approximately 40 percent in the number of people highly annoyed (as defined in the study) can be obtained by using these operational techniques. At DCA the number of people highly annoyed using the standard procedure was quite low, but it is significant that the minimum-impact case for Runway 36 reduced the number of people highly annoyed to zero by using a power cutback and a turning departure path. The evaluation procedures and methodology developed in this study represents an advance in acoustical state-of-the-art and should provide an effective and useful tool for determining aircraft noise impact upon the airport community.

The MF aircraft was developed by a series of studies which began with a comparison of 150-passenger, 2- vs 4-engine configurations designed for a 3000-foot field length. The 2-engine configuration proved to be slightly superior. The study progressed by comparing 2-engine MF aircraft designed for 3000-foot and 4000-foot field lengths. Concurrently, an acoustic/engine cycle trade study was conducted on engines with fan pressure ratios of 1.32, 1.45, and 1.57 using takeoff sideline noise as the acoustic criterion. These engines were examined with no acoustic treatment (hardwall)

and with nacelle wall treatment. The trade study included generation of uninstalled performance and weight estimates, preparation of installation drawings, calculation of installed engine performance, calculation of takeoff noise levels, and estimation of engine prices. At the outcome of the MF aircraft studies, it was concluded that an M-150-4000 aircraft with twin 1.57 FPR engines (nacelle wall treatment) should be used in the community noise impact phase of the study. The M-150-4000 and M-150-3000 aircraft had essentially the same noise impact, but the DOC of the M-150-3000 aircraft was approximately 18 percent higher and the mission fuel 24 percent greater.

A study was conducted to determine the sensitivity of the NASA STOL Systems Study final design E-150-3000 aircraft to changes in wing sweep and thickness ratio. During the NASA STOL Systems Study, it was determined that this aircraft was relatively insensitive to aspect ratio and that $AR = 8$ was near optimum. Similarly, it was found that wing sweep and wing thickness had little effect and that changing to an optimum wing (primarily a reduction in wing sweep) would result in approximately a one to two percent reduction in DOC. The insensitivity to wing geometry is partly due to the engine being selected for a field length and sideline noise requirement rather than for a cruise speed requirement.

A Douglas-developed computer program was used to generate takeoff and landing flight profiles for use in the noise impact studies. In this program, parameters can be varied to determine their effect on the flight path. The parameters varied were:

Takeoff

- | | |
|-----------------------------|--------------------------|
| a) Flap retraction altitude | d) Thrust cutback amount |
| b) Flap retraction rate | e) Amount of turning |
| c) Thrust cutback altitude | |

Landing

- a) Glide slope angle
- b) Change in slope angle - two segment approach
- c) Flap extension rate

The above program develops flight path data which is input to a Douglas-developed acoustic computer program which calculates noise contours and community noise impact.

The acoustic program uses predicted EPNL vs distance information together with the flight profile data to compute single-event EPNL contours as well as the total area enclosed by each contour. To evaluate the community noise impact, census data is required for each airport examined, and an annoyance factor, in terms of the percent of people highly annoyed, is computed as a function of EPNL. By definition, the summation of the annoyance factor times the population is the number of people highly annoyed in the vicinity of the airport in question.

A standard operational technique was established for both the MF and EBF aircraft. A low-impact operational procedure was then obtained as a result of parametric studies of the effects on noise impact of varying operational parameters, such as, flap retraction height and rate, and thrust cutback height and amount. These studies assumed a uniform population distribution. By superimposing the low-impact contour on a standard 7.5 minute U.S.G.S. topographical map with an overlay showing census tract population, it was possible to optimize or "fine-tune" the low-impact operational procedure to the specific airport community by varying takeoff flight techniques. The contour was shaped by varying the level of power cutback, cutback altitude and turn altitude and amount. Turns were made to follow

waterways, parks, railroads, etc., to avoid highly populated and noise sensitive areas. The final result was a minimum-impact procedure. No detailed optimization was made for the approach procedure since the size of the low-impact approach contour using a decelerating approach technique was found to be minimal.

Also studied (at Midway Airport) was the effect of oversizing by 10 percent the engines on the E-150-3000 aircraft. The objective was to reduce the noise impact by having steeper climb angles up to the point of thrust cutback. This oversized case resulted in an additional 8 percent reduction in the number of people highly annoyed at Midway, employing the same operational techniques used for the non-oversized case.

The typical noise impact reductions achieved by operational techniques for both aircraft were studied. However, the noise impact reduction for the M-150-4000 aircraft was less than that for the E-150-3000 aircraft. This is mainly due to the higher sideline noise produced by the M-150-4000 aircraft which increased the width of the noise contours.

The study methods used herein for aircraft operational noise alleviation provide a tool which can be used to help establish terminal area flight procedures. Although it was not applied in this study, the capability also exists to compare operational flight procedures on the basis of fuel consumption as well as noise impact to determine minimum energy procedures in the terminal area.

The accuracy is limited by the accuracy of the noise-impact prediction methodology, the validity of the noise annoyance function, and the census data base. Much work remains to be done to develop more accurate aircraft noise prediction methods, to improve and validate methods for predicting community response, and to standardize airport noise evaluation methodology.

2.0 INTRODUCTION

Past studies have shown the benefits of low fan pressure ratio engines and the use of acoustically-treated nacelles for reducing the noise generated by aircraft. This program used a $FPR = 1.25$ engine on the final design E-150-3000 aircraft from the NASA STOL Systems Study (Reference 1) and a $FPR = 1.57$ engine on a M-150-4000 aircraft. Both had acoustical treatment on the nacelle walls; however, the nacelle for the $FPR = 1.57$ engine was designed for aerodynamic performance and neither the inlet nor fan exhaust ducts were extended for further noise reduction. To reduce the community noise impact, this study investigated the effects of varying the aircraft operating procedures in the terminal area.

The objectives of this study were to:

- Determine an optimum engine cycle for a short-haul mechanical-flap airplane considering tradeoffs between acoustics, performance, and economics.
- Investigate aircraft operational techniques in the terminal airport area to minimize the noise impact on the community.
- Evaluate the noise impact of the study aircraft in four representative airport communities.

The study was conducted in four major steps as shown in Figure 2-1.

Aircraft trade studies were performed to select an optimum MF aircraft configuration, as well as to determine the effect of wing geometry and oversized engines on the EBF configuration.

STUDY PLAN

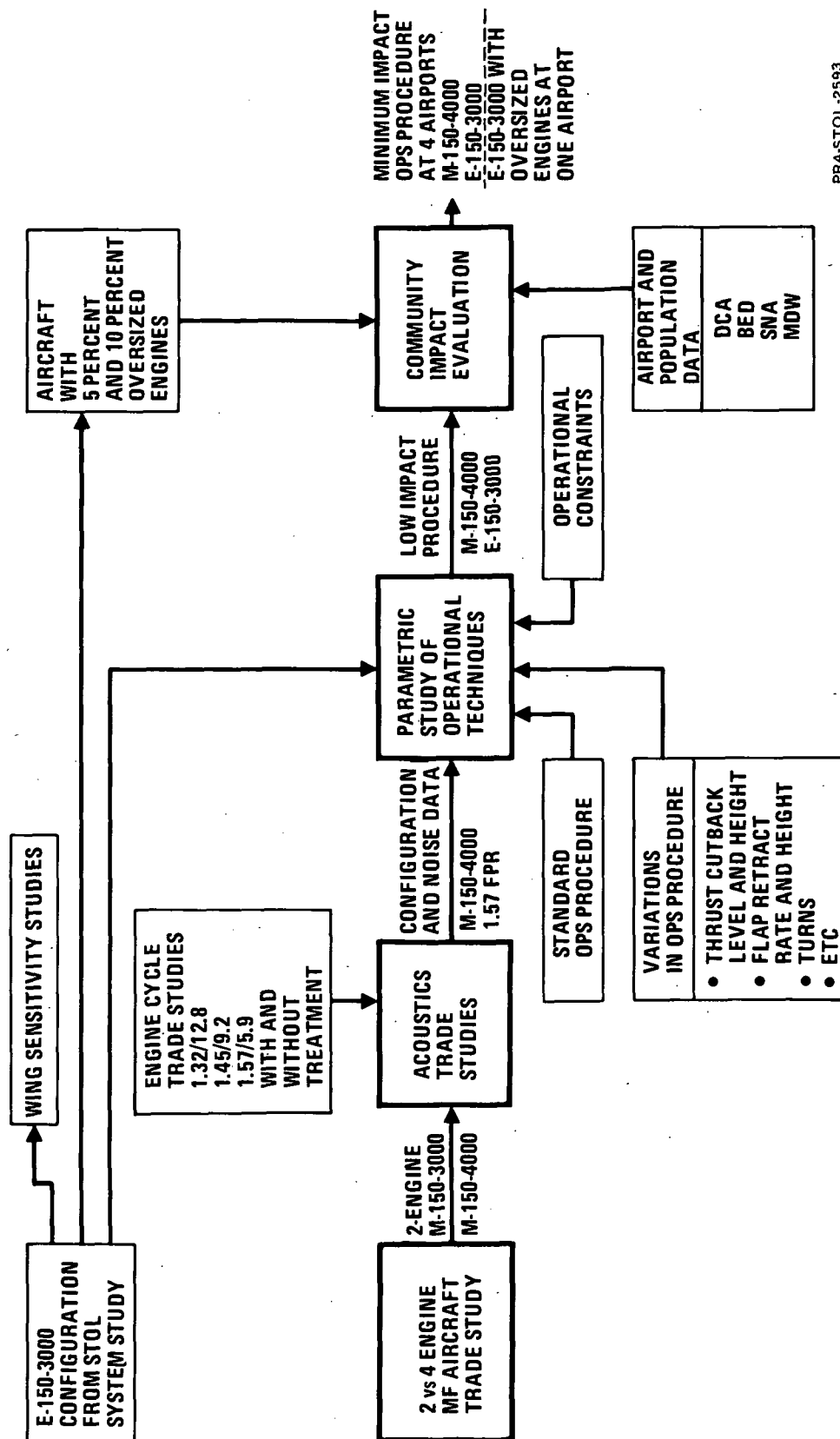


FIGURE 2-1.

For the acoustic trade study, three engine cycles, with and without acoustic treatment, were used to size the MF aircraft for two field lengths to form a matrix of twelve aircraft. From this study, the M-150-4000 aircraft was selected for further community noise impact analyses.

The parametric study of operational techniques was performed to determine the effect on community noise of various operational techniques for EBF and MF aircraft assuming a uniform population distribution. Low-impact procedures and noise contours resulted from these studies which were used as a starting point for the evaluation of community impact.

For the community impact evaluation, the aircraft operational techniques were optimized at selected airports (using census population data) to develop a minimum-impact procedure for a particular runway. As shown in Figure 2-1, the minimum impact procedure was developed for the EBF and MF aircraft at four study airports and for the EBF with oversized engines at one airport.

3.0 AIRCRAFT CONFIGURATION TRADE STUDIES

3.1 Mechanical-Flap (MF) Aircraft Configuration Study

A trade study was conducted on a 3000-foot (914 m) field length mechanical-flap aircraft to determine whether it would have lower direct operating costs as a two or a four-engine configuration. It was assumed that if the trade study showed a twin-engine configuration to be better at 3000-foot (914 m) field lengths it would also be better at 4000 feet (1219 m). If a four-engine configuration was superior at 3000 feet (914 m) then the same type of trade study would be necessary for the 4000-foot (1219 m) field length configurations.

Two aircraft were sized, a twin-engine and four-engine design. Both aircraft are high-wing configurations with engines mounted under the wings and are designed to carry 150 passengers over a 575 statute mile (926 km) stage length. Fairly long engine pylons allow elimination of flap cutouts, and two-segment tracked-motion flaps provide efficient low speed aerodynamic performance. Allison PD287-6 engines (1.32 FPR), as used in the acoustic trade study of the NASA Short-Haul STOL Systems Study (Reference 1), were utilized. The twin-engine design is shown in Figure 3-1. The four-engine configuration is similar except for the two additional engines.

A summary comparing the performance characteristics of the two aircraft is presented in Table 3-1. The four-engine configuration has a slightly lower gross weight (0.3%) and lower fuel consumption (2.5%) than the two-engine aircraft but DOC is 8 percent higher. The increased DOC is the result of higher total engine costs and engine maintenance. On the basis of this DOC difference, the two-engine configuration was selected for parametric aircraft sizing during the acoustic trade study for field lengths of both 3000 and 4000 feet (914 and 1219 m).

GENERAL ARRANGEMENT

M-150-3000 — TWO PD287-6 ENGINES

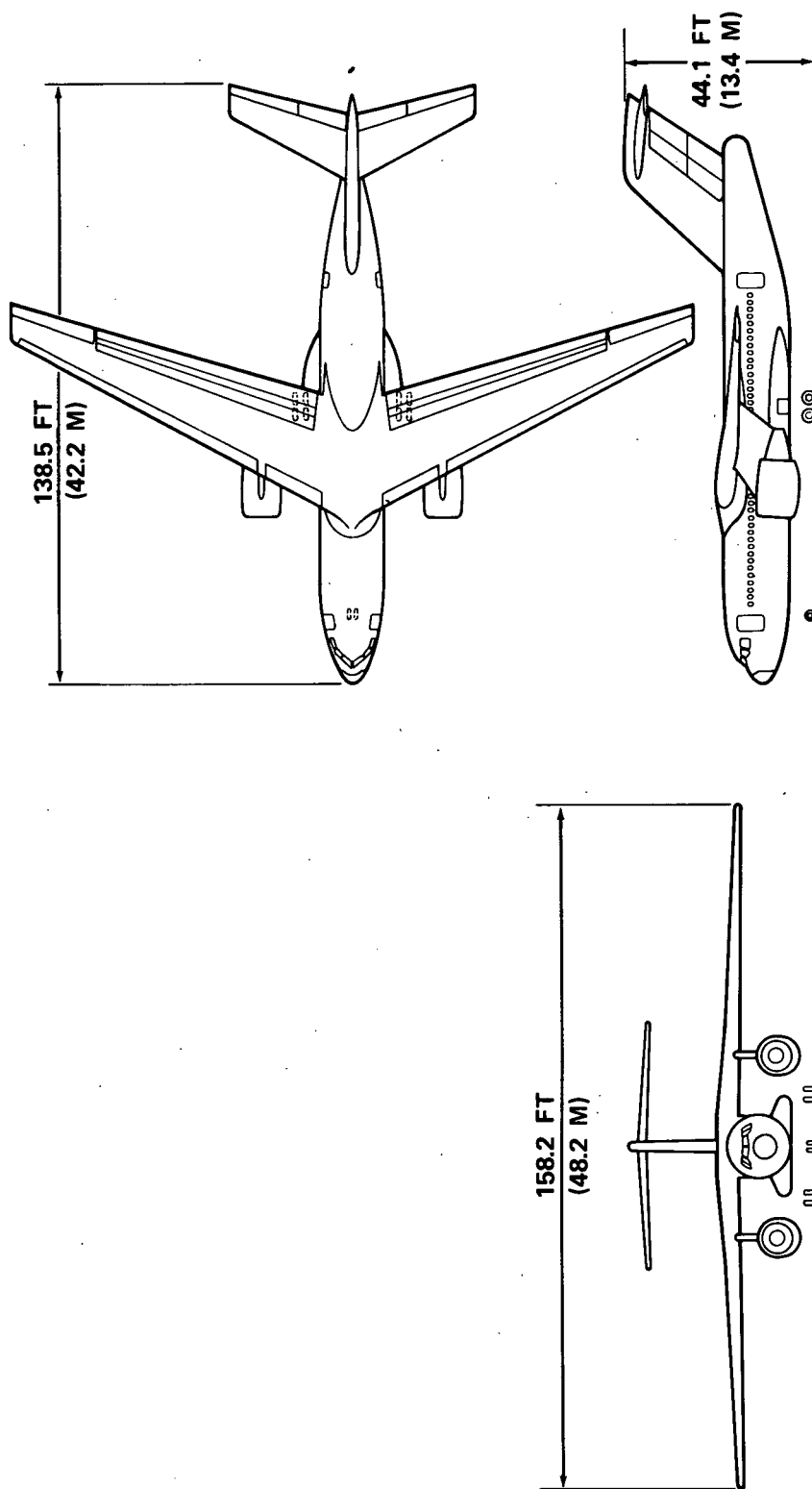


FIGURE 31.

PR3-STOL-2045

TABLE 3-1

TWO Vs FOUR ENGINE MECHANICAL-FLAP STOL AIRCRAFT CONFIGURATION STUDY

PERFORMANCE SUMMARY

150 Passengers, 3000 ft (914 m) Field Length

PD287-6 Engines, Wall Acoustic Treatment

		2 Engine Configuration	4 Engine Configuration
Design TOGW	lb (kg)	173,550 (78,720)	172,900 (78,430)
Wing Area	ft ² (m ²)	2,878 (267)	2,867 (266)
Thrust/Engine	lb (N)	33,060 (147,100)	15,130 (67,300)
Wing Loading	lb/ft ² (kg/m ²)	60.3 (294)	60.3 (294)
Thrust to Weight Ratio		0.381	0.350
OEW	lb (kg)	125,260 (56,820)	125,110 (56,750)
Wing Aspect Ratio		8.7	8.7
Cruise Mach Number		0.66	0.64
Cruise Altitude	ft (m)	28,000 (8,500)	26,000 (7,900)
DOC @ 575 st. mi. (926 km)	¢/ASSM (¢/ASKM)	2.21 (1.37)	2.39 (1.48)
Block Fuel @ 575 st. mi. (926 km)	lb (kg)	13,390 (6070)	13,030 (5910)

3.2 Externally-Blown-Flap Aircraft Wing Geometry Sensitivity

A study was completed to determine the sensitivity of a 150-passenger, 3000-foot (914 m) field length, externally-blown-flap STOL aircraft to independent variations in wing geometry; i.e., aspect ratios, average wing thickness ratios and wing sweeps. The sizing calculations were performed in a manner consistent with the methods described in Reference 1, Appendix B of Volume II. The sized aircraft presented below are all at wing loading and thrust-to-weight ratio combinations for balanced takeoff and landing field length. The E-150-3000 final design aircraft with 1.25 FPR engines, as described in Volume II of Reference 1, was used as the basepoint for the study.

3.2.1 Aspect Ratio Study - The choice of wing aspect ratio is based on a tradeoff between increased aerodynamic efficiency and increased wing structural weight associated with an increase in aspect ratio. The influence of aspect ratio on the sizing of a 150-passenger, 3000-foot (914 m) field length, externally-blown-flap STOL aircraft was examined in the NASA STOL Short-Haul Systems Study (Reference 1). Minimum direct operating cost occurs at an aspect ratio of 8 for this particular aircraft. However, the variation of direct operating cost with aspect ratio is very small, being less than 0.5 percent for a variation in aspect ratio from 7 to 9.

3.2.2 Wing Thickness Ratio Study - The effects on aircraft sizing of increasing wing thickness ratio are primarily due to decreasing wing structural weight and increasing parasite and compressibility drag. Induced drag and low speed aerodynamic efficiency are not significantly affected by varying wing thickness ratio.

Aircraft were sized with average wing thickness ratios of 0.10,

0.1375 and 0.16. Minimum direct operating cost occurred at an average wing thickness ratio of .15. However, variation of average wing thickness ratio over the range examined resulted in a maximum change in direct operating cost on the order of 1 percent.

3.2.3 Wing Sweep Study - Increasing wing sweep affects aircraft sizing by decreasing parasite and compressibility drag, increasing induced drag, degrading low-speed aerodynamic efficiency and increasing wing structural weight. Effects on aircraft sizing due to wing sweep variation were determined by sizing aircraft for wing sweeps of 5.6, 15 and 25 degrees (0.10, 0.26, and 0.44 rad). The variation of direct operating cost with wing sweep was found to be less than 1 percent for the range of wing sweeps studied. The lowest DOC was obtained with the lowest wing sweep since the high thrust lapse of the 1.25 FPR engines prohibit high cruise speeds.

3.2.4 Conclusions - Direct operating cost (DOC) is not particularly sensitive to aspect ratio, wing thickness ratio or wing sweep for the E-150-3000 aircraft with 1.25 FPR engines. This conclusion is valid when the aircraft is sized by the design field length requirement rather than for a specific cruise speed capability. Sizing for a given cruise Mach Number would cause DOC to be more sensitive to wing geometry.

An aspect ratio of 8, wing thickness ratio of 0.15 and a wing sweep of 5.6° (0.10 rad) appear to be near optimum wing geometry for this specific aircraft based on minimizing DOC at the design range. The resulting reduction in DOC compared to the final design E-150-3000 aircraft from the NASA STOL Short-Haul Systems Study would only be about one percent.

3.3 Externally-Blown-Flap Aircraft with Oversized Engines

A trade study was conducted to determine if increasing the engine thrust size over that required to meet takeoff and landing field length requirements would reduce community noise impact for a short-haul aircraft. Increasing engine size tends to increase sideline and approach noise but the increased climb gradient associated with higher aircraft thrust-to-weight ratio may result in a significant reduction in takeoff noise impact.

The E-150-3000 final design aircraft from the NASA Short-Haul Systems Study (Reference 1) was chosen as a basepoint. This aircraft was sized on the basis of minimum DOC which occurs at the intersection of the landing and takeoff critical lines, i.e., takeoff field length = landing field length = 3000 feet (914 m), as illustrated in Figure 3-2. Two additional aircraft were sized having approximately 5 and 10 percent higher thrust engines than the base aircraft. To minimize DOC penalties, design points for these two additional aircraft were selected on the landing critical line, i.e., increasing wing loading as engine thrust size is increased to maintain a 3000-foot (914 m) landing field length. There is essentially no increase in DOC associated with the use of larger engines. The increase in cruise Mach number and hence block speed compensates for the aircraft weight increase in determining DOC.

In the area of noise reduction, there is an additional benefit associated with the use of oversized engines. Since the aircraft with oversized engines are not takeoff critical, a takeoff flap setting lower than that required for minimum field length may be selected. The lower flap angle will result in increased initial climb gradient and, for an EBF aircraft, a reduction in flap interaction noise. Most of the reduction in noise

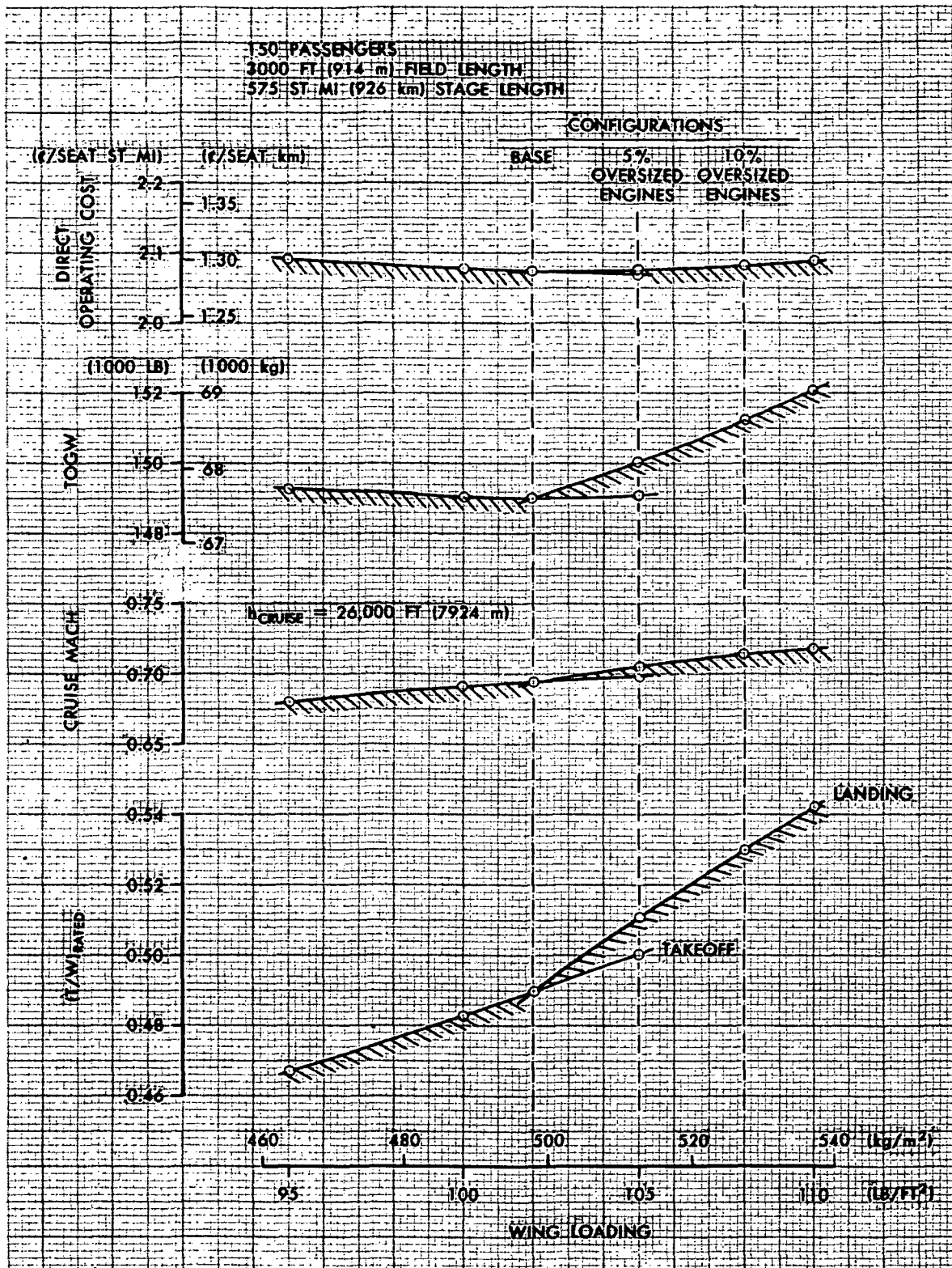


FIGURE 3-2. SIZING FOR EXTERNALLY BLOWN FLAP WITH OVERSIZED ENGINES

impact is obtained with 5-percent oversized engines. Engine oversizing by more than 10 percent is not expected to produce further noise reductions.

A penalty associated with the use of larger engines, other than higher aircraft weights and initial cost, is an increase in fuel consumption. A 10 percent increase in engine size is accompanied by a 6 percent increase in block fuel at the design range of 575 statute miles (926 m).

4.0 PROPULSION SYSTEM AND ACOUSTIC TRADE STUDY

4.1 Objectives

A trade study was conducted to determine the effect of engine cycle characteristics and degree of acoustic treatment on aircraft sizing, economics and noise level for 150-passenger, 3000-foot (914 m) and 4000-foot (1219 m) field length, mechanical-flap aircraft.

Selection of the mechanical-flap aircraft configuration used for the study of operational noise reduction techniques (Section 5.0) was based on the results of this trade study.

4.2 Engine Definition and Performance

4.2.1 Engine Cycles - Three engine cycles were selected for the study. Fan pressure ratio was the primary independent variable since noise, thrust lapse, and cruise performance are strongly dependent on this parameter. Maximum turbine inlet temperatures were the same for all engines to maintain the same technology level, and component efficiencies were comparable to those of the QCSEE engines of Reference 1 for consistency in the two studies (see Section 4.2.2). Bypass ratio was established at a value which resulted in a primary jet exhaust velocity at takeoff sufficiently low that the primary jet was not the dominant noise source.

The fan pressure ratio range studied was 1.32 to 1.57. The value of 1.32 was selected because it was the upper limit at which engine companies had previously indicated variable-pitch fans could be operated in the reverse-thrust mode. The ability to obtain reverse-thrust by use of reverse

pitch has advantages in weight, cost, and maintenance over cascade or other nacelle-mounted thrust reversers. Engines with lower fan pressure ratios were not considered because they have less cruise thrust and larger diameters, which, particularly with a two-engine aircraft, can cause installation and ground handling problems.

The highest takeoff fan pressure ratio engine used in the study was 1.57. This level is typical of current technology fans which have noise levels of the order of (FAR 36) - 10 dB. Also, an engine with this fan pressure ratio and near optimum bypass ratio of 5.9 was available and had been used in a similar trade study on an EBF aircraft in Reference 1. A 1.45 fan pressure ratio was selected for an intermediate value. Variable-area fan nozzles were used with the 1.32 and 1.45 FPR engines to maximize available cruise thrust.

Studies were conducted to determine bypass ratios for the 1.32 and 1.45 FPR engines. The Allison PD287-6 engine (Reference 3) has a FPR of 1.32 but a bypass ratio restrained by a requirement for a primary velocity of 700 ft/sec (213 m/sec). This cycle was designed for 95 EPNdB noise level for a propulsive-lift installation, where noise is more sensitive to exhaust velocity than it is with an installation such as that on the MF aircraft, where the engine exhaust does not impinge on the flap. Using a lower bypass ratio with a higher primary exhaust velocity for the 1.32 FPR fan increases the cruise thrust and the specific thrust at takeoff, and makes the engine less sensitive to losses.

Figure 4-1 shows the increase in specific thrust and primary exhaust velocity at takeoff power as bypass ratio is decreased, for an engine

SPECIFIC THRUST AND PRIMARY VELOCITY AT TAKEOFF

FAN PRESSURE RATIO = 1.32

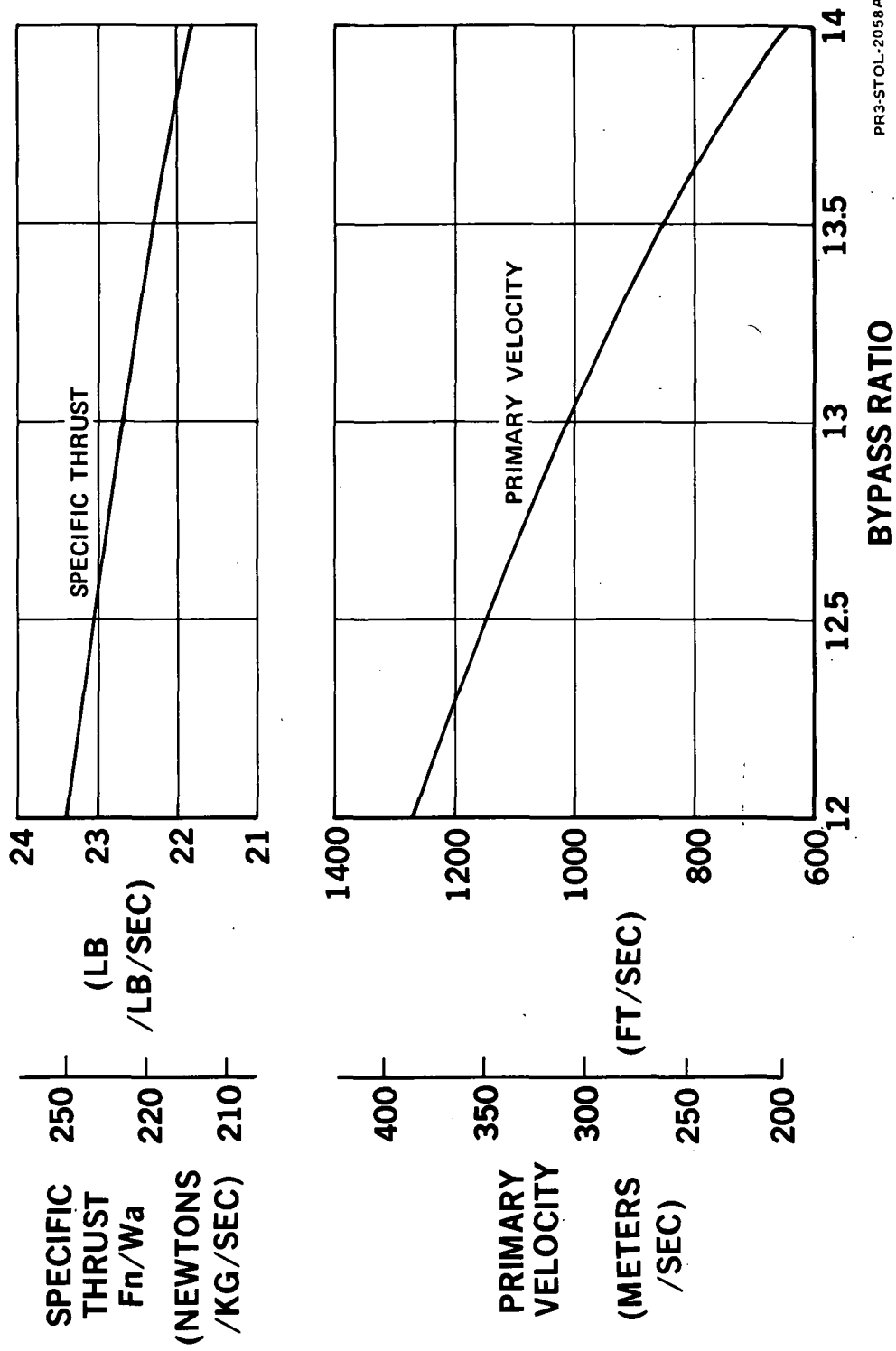


FIGURE 4-1.

with a fan pressure ratio of 1.32. The noise penalty associated with the primary velocity is shown in Figure 4-2 as a function of bypass ratio, with relative values of thrust and specific fuel consumption. Both the primary jet noise and the so-called "core" noise are functions of the primary exhaust velocity in the noise estimation methods used in this study. The results shown in Figure 4-2 led to the selection of a value of 12.8 as a bypass ratio for the engine with a fan pressure ratio of 1.32. At this point the cruise SFC was at a minimum value. At lower bypass ratios, higher take-off specific thrust (which results in better engine thrust/weight) and more cruise thrust are available, but the primary velocity increases to a range where the primary jet noise would be a significant factor in the total noise level of an engine with acoustical treatment.

The gains in engine performance by going to a bypass ratio of 12.8 from the value of 13.8 are summarized in Table 4-1 below.

TABLE 4-1
ENGINE PERFORMANCE CHANGE
12.8 BPR VS. 13.8 BPR

	<u>Change Due to Lower BPR</u>
Fan Diameter	- 2.0%
Engine Thrust/Weight	+ 2.3%
Climb Thrust (20,000 ft; 0.6 M_0)	+ 3.0%
Max. Cruise Thrust (30,000 ft; 0.7 M_0)	+ 4.5%
Min. SFC @ Cruise	- 1.4%

A study of the effect of bypass ratio on an engine cycle having a fan pressure ratio of 1.45 was conducted in a similar manner. A bypass

EFFECT OF BYPASS RATIO WITH 1.32 FPR FAN

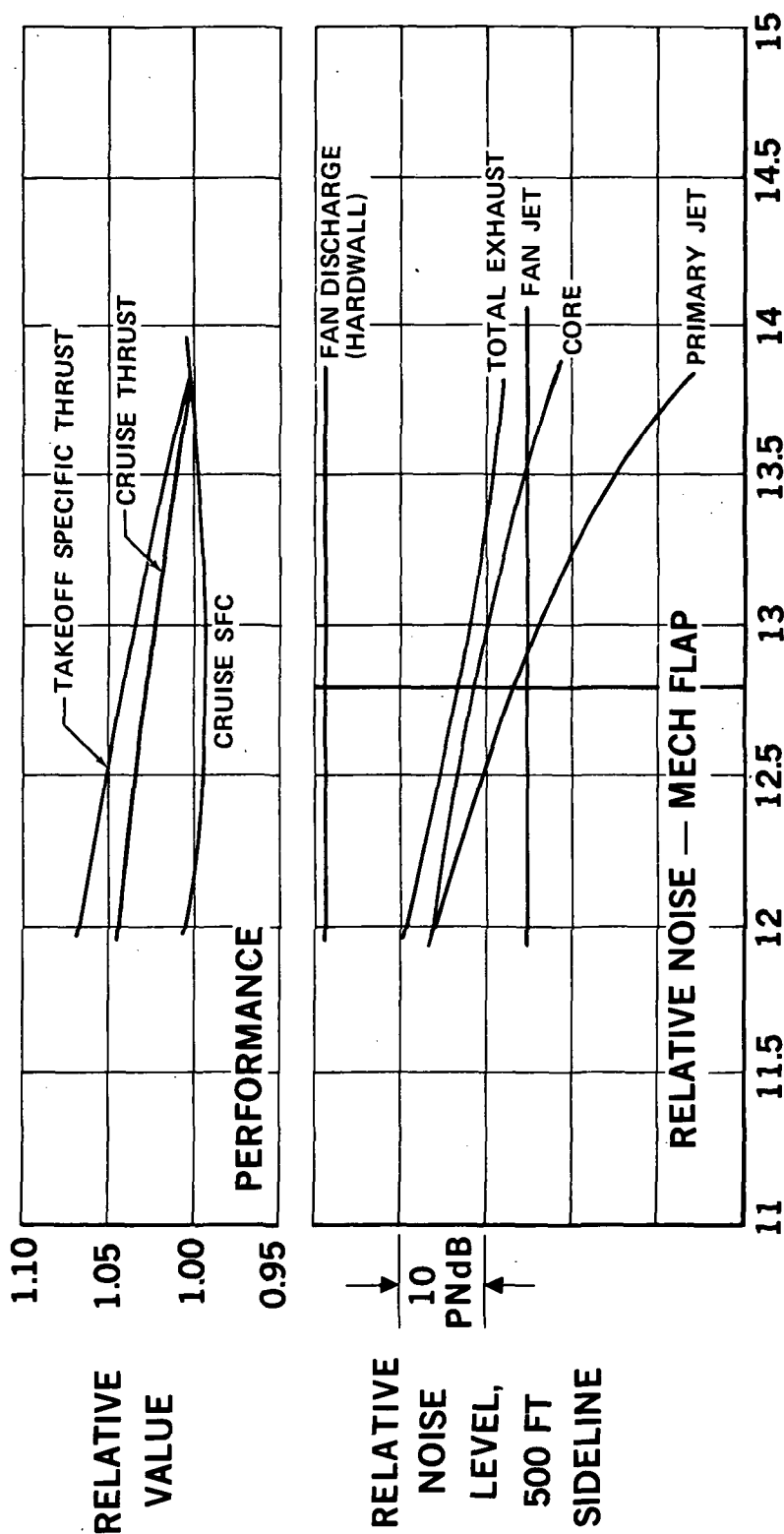


FIGURE 4-2.

PR3-STOL-2052 B

ratio of 9.2 was selected for the 1.45 FPR engine to be used in the acoustic trade study. Table 4-2 summarizes pertinent characteristics of the engines considered in the trade study.

4.2.2 Propulsion Installation for MF Aircraft - Engine installation drawings were made for the three study engine cycles. The nacelle lines were determined on the basis of aerodynamic performance using methods utilized on the DC-9 and DC-10. Both "hard-wall" and treated duct installations were evaluated in the noise level - DOC trade study using the same dimensions for the installations. For the treated installation, acoustical lining was applied to the inlet and exhaust duct walls wherever practical. The 9.2/1.45 and 5.9/1.57 engines had longer fan exhaust ducts than required for aerodynamic performance because of the use of thrust reversers, and therefore, had more area for sound treatment. The nacelles were located to attain the best nacelle/wing drag characteristics consistent with avoiding impingement of the hot jet exhaust on the flap surfaces during takeoff and landing.

Engine installations for a mechanical-flap aircraft are shown in Figures 4-3, 4-4, and 4-5. Figure 4-3 is a vertical section view of the nacelle designed for a 35,000 pound (156,000 N) thrust, variable-pitch fan engine with a fan pressure ratio of 1.32 and a bypass ratio of 12.8. (The installation shown is with acoustic treatment. The untreated case for this engine is identical except the acoustic treatment is deleted.) Figure 4-4 shows the acoustically-treated installation of the 9.2/1.45 fixed-pitch fan engine at a rated thrust of 35,000 pounds (156,000 N) and Figure 4-5 is a 30,000 pound (133,000 N) engine with a fixed-pitch fan, a FPR of 1.57, and a bypass ratio of 5.9.

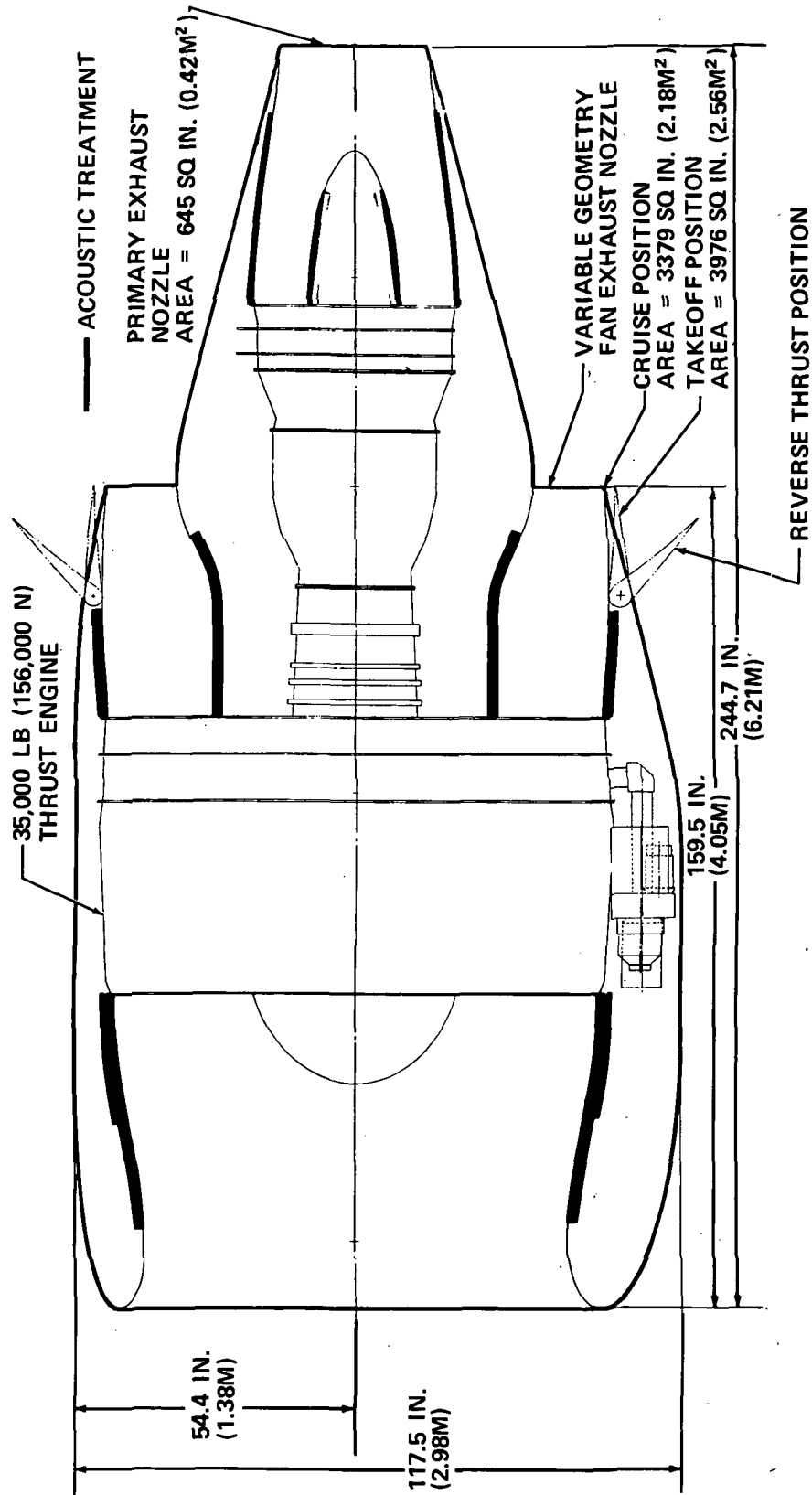
TABLE 4-2
SUMMARY OF CHARACTERISTICS OF ENGINES
IN ACOUSTIC TRADE STUDY

Designation	12.8/1.32	9.2/1.45	5.9/1.57
FPR	1.32	1.45	1.57
Bypass Ratio	12.8	9.2	5.9
Overall Pressure Ratio	20.0	21.8	22.7
Fan Tip Speed	925 ft/sec (282 m/sec)	1250 ft/sec (381 m/sec)	1550 ft/sec (472 m/sec)
Specific Thrust, F_n/w_{a2}	22.9 (224 N/kg/sec)	26.5 (260 N/kg/sec)	30.4 (298 N/kg/sec)
Thrust Weight	6.69 lbs/lb	6.74 lbs/lb	6.92 lbs/lb
Above values at SLS, std. Day			
<u>Cruise Thrust*</u> <u>Takeoff Thrust</u>	0.20	0.22	0.26
Cruise SFC*	0.59	0.61	0.60
Fan Configuration	Variable- Pitch	Fixed- Pitch	Fixed- Pitch
Nozzle Configuration	Variable- Area Fan Nozzle	Variable- Area Fan Nozzle	Fixed Area Nozzles

* @ 30,000 ft., $M_0 = 0.7$

NACELLE WITH 12.8/1.32 ENGINE

VARIABLE PITCH FAN



PR3-STOL-2034A

FIGURE 4-3

NACELLE WITH 9.2/1.45 ENGINE

FIXED PITCH FAN

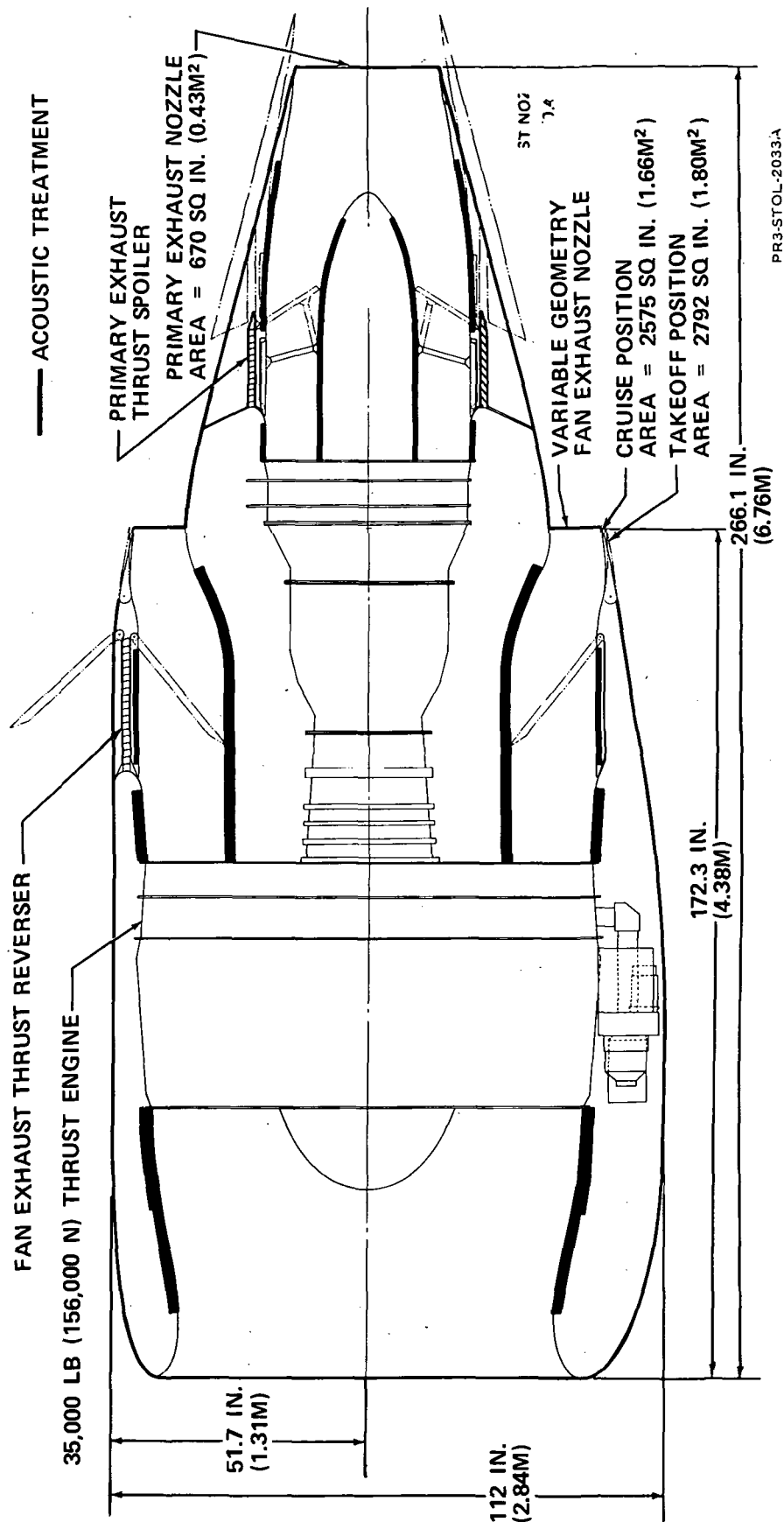
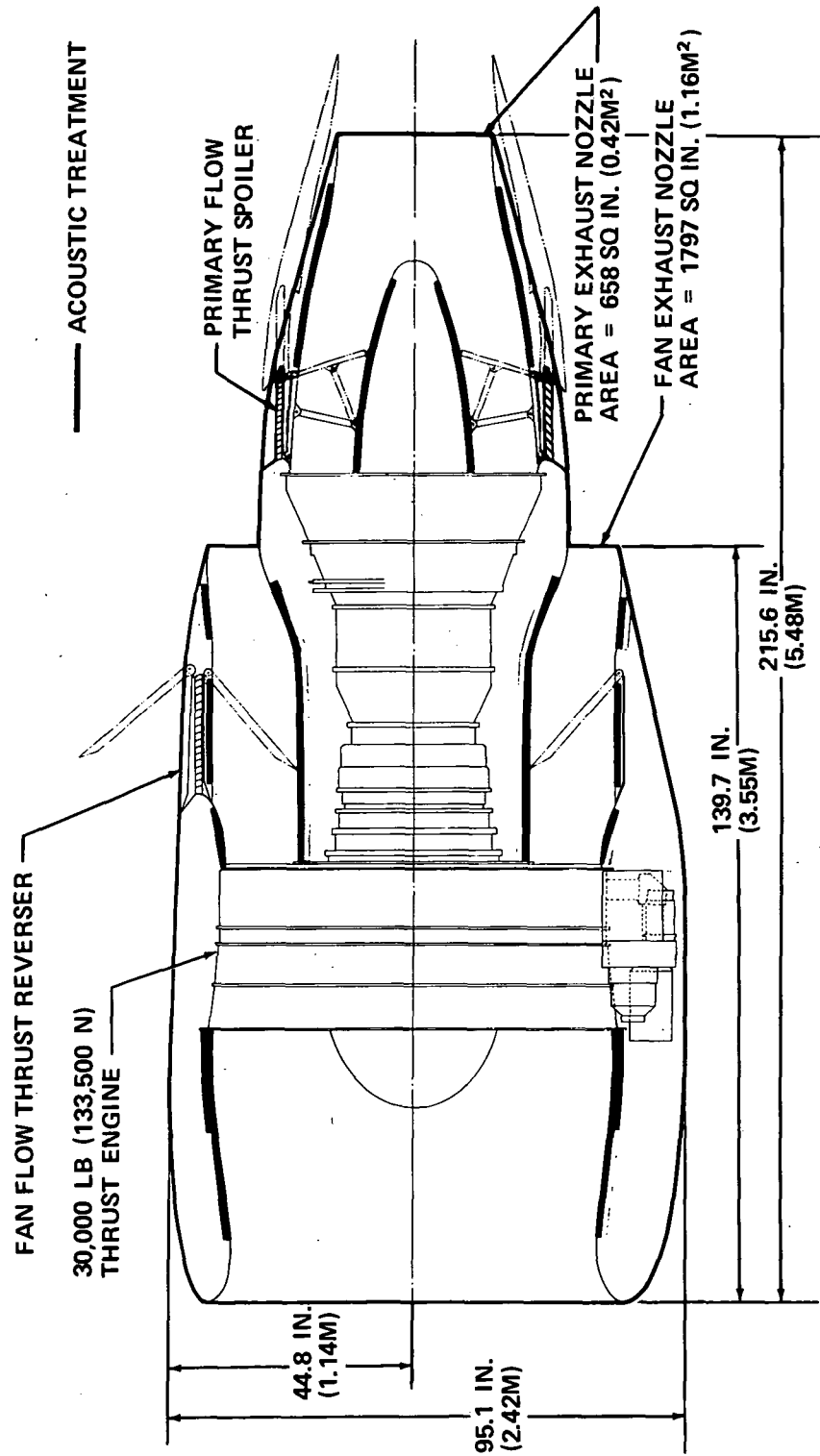


FIGURE 4-4

NACELLE WITH 5.9/1.57 ENGINE

FIXED PITCH FAN



PR3-STOL-2035A

FIGURE 4-5

4.3 Aircraft Sizing

A matrix of twelve mechanical-flap aircraft were sized based on the methods and ground rules described in Appendix A.1 of Reference 4. This matrix consisted of:

Design Field Length: 3000 ft. (914 m), 4000 ft. (1219 m)
Engine FPR: 1.32, 1.45, 1.57
Acoustic Treatment: None (hardwall), nacelle wall treatment

A twin-engine configuration was selected for all twelve aircraft based on the results of the mechanical-flap configuration trade study (see Section 3.1). A typical sizing plot of each aircraft in the matrix is shown in Figure 4-6. This plot is for a 4000-foot (1219 m) field length MF aircraft with 1.32 FPR engines without acoustic treatment. Design points were selected on the basis of minimum DOC which occurs at the W/S and T/W where takeoff and landing performance are equally critical. There is, however, very little penalty in terms of aircraft weight or operating cost associated with engine oversizing (increased T/W).

A summary of aircraft performance characteristics for the 4000-foot (1219 m) MF aircraft is contained in Table 4-3. A noticeable increase in Mach number capability is associated with higher engine FPR. This is due to the lower thrust lapse rate of the higher FPR engines. There is also very little penalty in terms of either weight or DOC due to the use of engine nacelle wall acoustic treatment. This level of treatment does not add significantly to engine installation weights nor have much impact on engine thrust and SFC.

Figure 4-7 shows the impact of engine FPR on direct operating

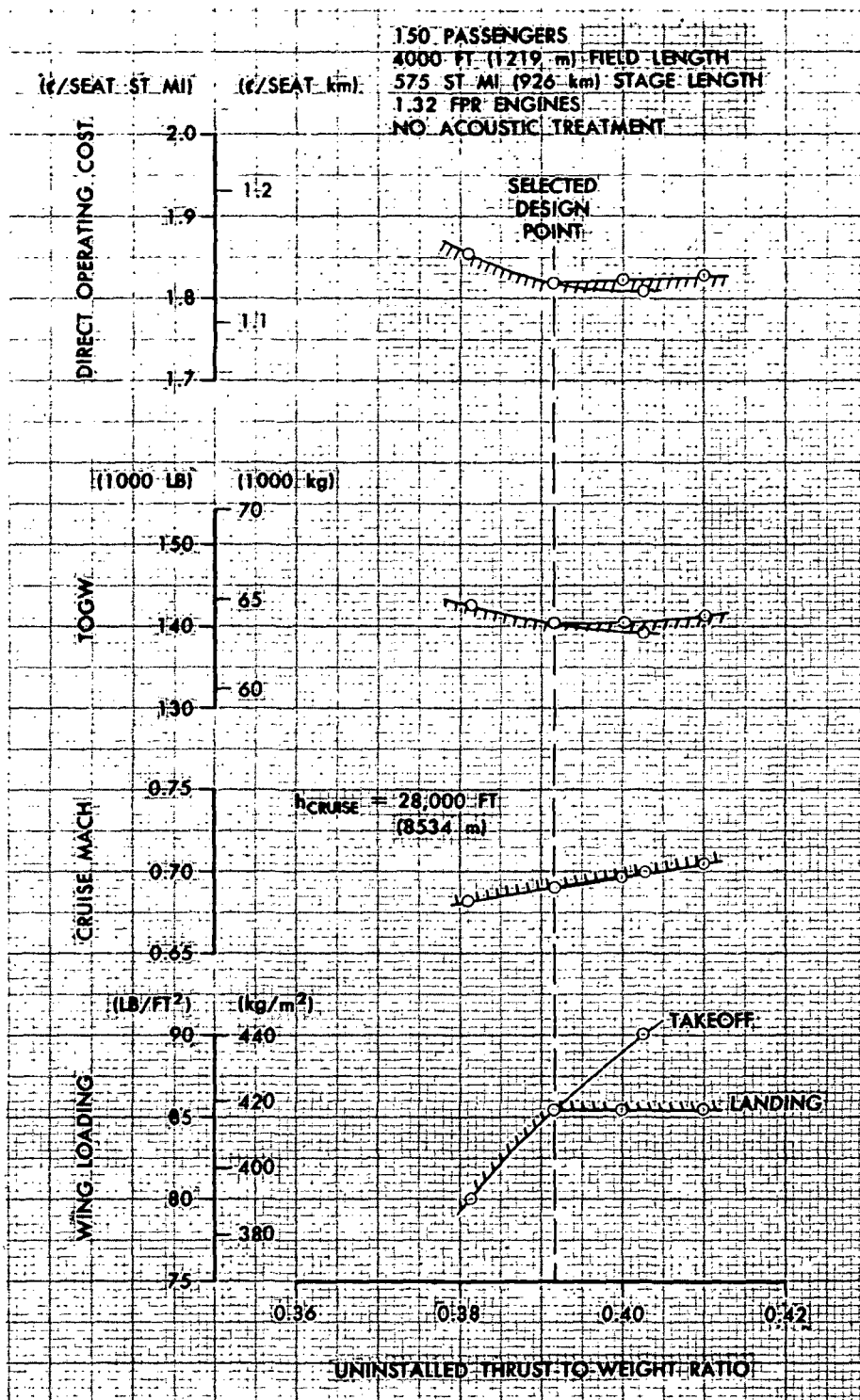


FIGURE 4-6. AIRCRAFT SIZING – M-150-4000

Table 4-3

ACOUSTIC TRADE STUDY AIRCRAFT SIZING
Twin-Engine Mechanical-Flap Configuration
4000-Foot (1219 m) Field Length

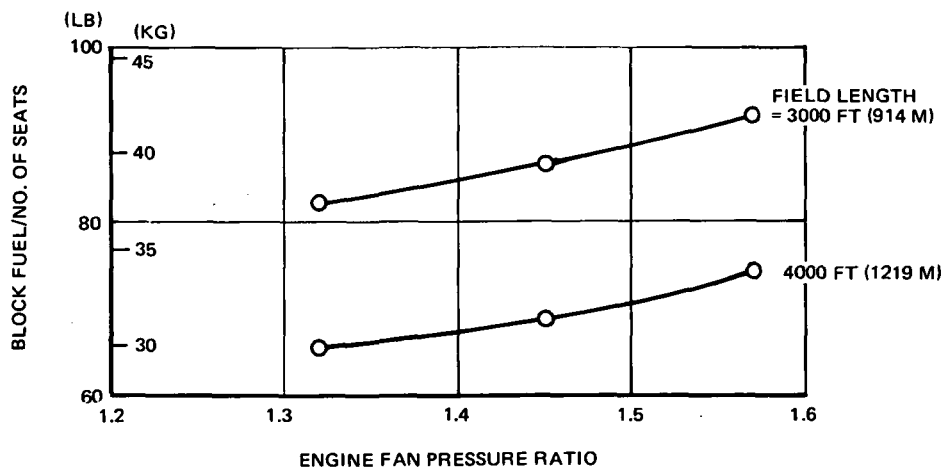
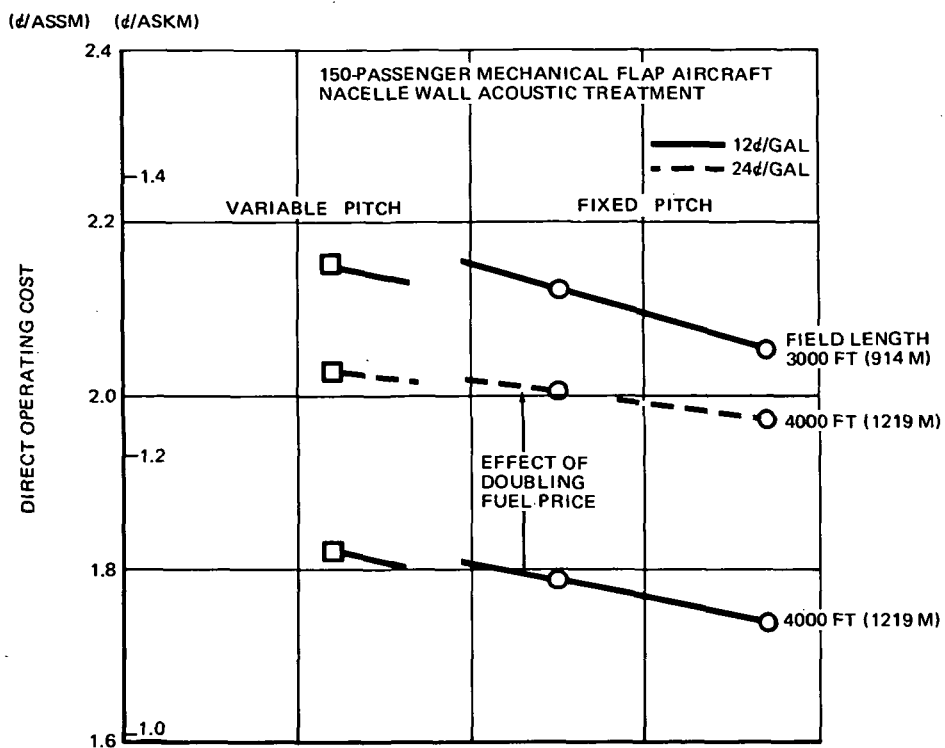
Engine FPR	1.32	1.45	1.57	1.32	1.45	1.57
Engine Treatment	None	None	None	Wall	Wall	Wall
Gross Weight	Lb. (kg)	140,300 (63,600)	144,000 (65,300)	143,500 (65,100)	144,200 (65,400)	143,600 (65,100)
Wing Area	Ft ² (m ²)	1,641 (152.4)	1,684 (156.4)	1,678 (155.9)	1,687 (156.7)	1,679 (156.0)
Thrust/Engine	Lb. (N)	27,490 (122,300)	27,540 (122,500)	26,780 (119,100)	27,670 (123,100)	26,870 (119,500)
W/S	Lb/Ft ² (kg/m ²)	85.5 (417.4)	85.5 (417.4)	85.5 (417.4)	85.5 (417.4)	85.5 (417.4)
T/W		0.392	0.383	0.373	0.384	0.374
OEW	Lb. (kg)	96,200 (43,640)	99,060 (44,930)	97,470 (44,210)	99,210 (45,000)	97,550 (44,250)
AR		8.7	8.7	8.7	8.7	8.7
M _{cr}		0.69	0.71	0.77	0.71	0.77
H _{cr}	Ft. (m)	28,000 (8,534)	30,000 (9,144)	30,000 (9,144)	30,000 (9,144)	30,000 (9,144)
DOC @ 575 St. Mi. (926 km)	φ/ASSM (φ/ASKM)	1.82 (1.13)	1.79 (1.11)	1.73 (1.07)	1.79 (1.11)	1.74 (1.08)

cost and aircraft fuel consumption for a 575 statute mile (926 km) stage length. The DOC for the 4000-foot (1219 m) field length aircraft with 1.57 FPR engines is approximately 4 percent lower than the DOC for the aircraft with 1.32 FPR engines based on a fuel price of 12 cents per gallon (31.7 \$/m³). Figure 4-7 also shows that higher priced fuel reduces the advantage of the high FPR engines. With the fuel price at 24 cents per gallon (63.4 \$/m³) the DOC advantage of the aircraft with 1.57 FPR engines over that with 1.32 FPR engines is reduced to approximately 3 percent.

4.4 Acoustic Analysis

4.4.1 Aircraft Noise Definition - Aircraft noise can be broadly classified into three categories; noise produced by the turbulence associated with the passage of a large body (the aircraft) through the ambient air, propulsive noise produced by the aircraft engines and, in the case of an EBF aircraft, propulsive-lift system (PLS) noise produced by directing the engine exhaust over or under the wing and flap surfaces to augment the lift characteristics of the aircraft. Of these three components the latter two are considered the most important for STOL-type aircraft.

Noise from a turbofan engine can be subdivided into internally-generated high-frequency turbomachinery noise and low-frequency core noise produced by the combustion process, and externally-generated jet noise produced by the turbulent mixing of the high velocity exhaust gases with the ambient air. Noise from propulsive-lift systems is produced by the direct impingement of the engine exhaust gases on the wing and flap surfaces. Internally-generated turbomachinery noise can usually be suppressed by the installation of acoustic materials in the engine nacelle, whereas jet noise and PLS noise are not easily suppressed.



DOC AND FUEL CONSUMPTION COMPARISON

FIGURE 4-7

4.4.2 500-Foot Sideline Noise Levels - From the NASA STOL Systems Study (Reference 1) the engine cycle selected for the E-150-3000 aircraft had a FPR = 1.25. The maximum EPNL, on a 500-foot (152 m) sideline, for the final design version of this aircraft is estimated to be 97 EPNdB. The methods used to evaluate the sideline noise characteristics of the MF trade study engine cycles were the same as those used to evaluate the EBF aircraft. Core jet velocities were kept low to reduce jet and core noise and to ensure that the resultant noise levels would be dominated by the fan, which can be suppressed by the use of nacelle acoustic treatment. The takeoff noise levels on a 500-foot (152 m) sideline for the M-150-3000 and M-150-4000 aircraft are shown in Tables 4-4 and 4-5. These tables list the component noise levels in terms of PNL, with and without nacelle acoustic treatment, the resultant peak inlet radiated PNL, peak aft radiated PNL, and estimated peak EPNL on a 500-foot (152 m) sideline. The difference in untreated fan noise levels for the three engine cycles was partially offset by the greater amount of acoustic treatment installed in the higher fan pressure ratio engines. It should be emphasized that the nacelles were not designed for best acoustics as was done in the NASA STOL Systems Study (Reference 1). Minimum drag was the primary criterion with the thrust reverser installation influencing the amount of treatment in the FPR = 1.45 and 1.57 designs.

TABLE 4-4
500-FT SIDELINE NOISE COMPARISON
M-150-3000

NOISE SOURCE	FPR = 1.32		FPR = 1.45		FPR = 1.57	
	UNTRTD	TRTD	UNTRTD	TRTD	UNTRTD	TRTD
Fan Inlet PNL	98.5	94.0	104.0	100.0	104.5	100.0
Fan Exhaust PNL	105.5	101.0	107.0	99.5	107.5	99.5
Turbine PNL	92.0	85.0	92.5	81.5	93.5	86.5
Core PNL	87.5	87.5	89.5	89.5	95.0	95.0
Jet PNL	84.5	84.5	90.0	90.0	98.0	98.0
Peak Inlet PNL	99.5	95.0	104.5	100.5	105.0	101.0
Peak Aft PNL	106.0	101.5	107.5	101.0	108.5	103.0
EPNL	104.0	99.5	105.5	99.0	106.5	101.0

TABLE 4-5
500-FT SIDELINE NOISE COMPARISON
M-150-4000

NOISE SOURCE	FPR = 1.32		FPR = 1.45		FPR = 1.57	
	UNTRTD	TRTD	UNTRTD	TRTD	UNTRTD	TRTD
Fan Inlet PNL	98.0	93.5	103.5	99.5	104.0	99.5
Fan Exhaust PNL	105.0	100.5	106.5	99.0	107.0	99.0
Turbine PNL	91.5	84.5	92.0	81.0	93.0	86.0
Core PNL	87.0	87.0	89.0	89.0	94.5	94.5
Jet PNL	84.0	84.0	89.5	89.5	97.5	97.5
Peak Inlet PNL	99.0	94.5	104.0	100.0	104.5	100.5
Peak Aft PNL	105.5	101.0	107.0	100.5	108.0	102.5
EPNL	103.5	99.0	105.0	98.5	106.0	100.5

4.5 Summary of Results

For the engine cycles studied, FPR = 1.32, 1.45 and 1.57, several general trends were noted.

The aircraft with 1.57 FPR engines had the highest cruise speed capability and lowest direct operating costs. The DOC advantage of approximately 4 percent compared to the 1.32 FPR engined aircraft is based on a 1972 fuel price of 12 ¢/gallon (31.7 \$/m³). Any significant increase in fuel price will tend to narrow this DOC difference due to the higher fuel consumption of the high FPR engines.

Sideline noise levels were slightly higher for the aircraft with the highest FPR engines. With the incorporation of nacelle acoustic linings, the 1.57 FPR engined aircraft are only 2 EPNdB noisier than the aircraft with the quietest engine studied. There were essentially no weight or DOC penalties associated with the use of nacelle wall acoustic treatment provided overall nacelle dimensions were not increased.

The 4000-foot (1219 m) field length aircraft are 0.5 EPNdB quieter in terms of sideline noise than those with 3000-foot (914 m) field lengths. This is due to the smaller engine thrust size and higher takeoff speeds of the 4000-foot (1219 m) field length airplanes. The higher takeoff speeds reduce the time duration factor used in EPNdB calculations. In addition, the DOC for the 3000-foot (914 m) aircraft was 18 percent higher than the 4000-foot (1219 m) aircraft and the mission fuel 24 percent greater.

From these results, the twin-engine 4000-foot (1219 m) mechanical-flap aircraft with 1.57 FPR engines was selected to evaluate techniques for noise reduction along with the E-150-3000 aircraft.

5.0 OPERATIONAL TECHNIQUES FOR NOISE REDUCTION

5.1 Introduction

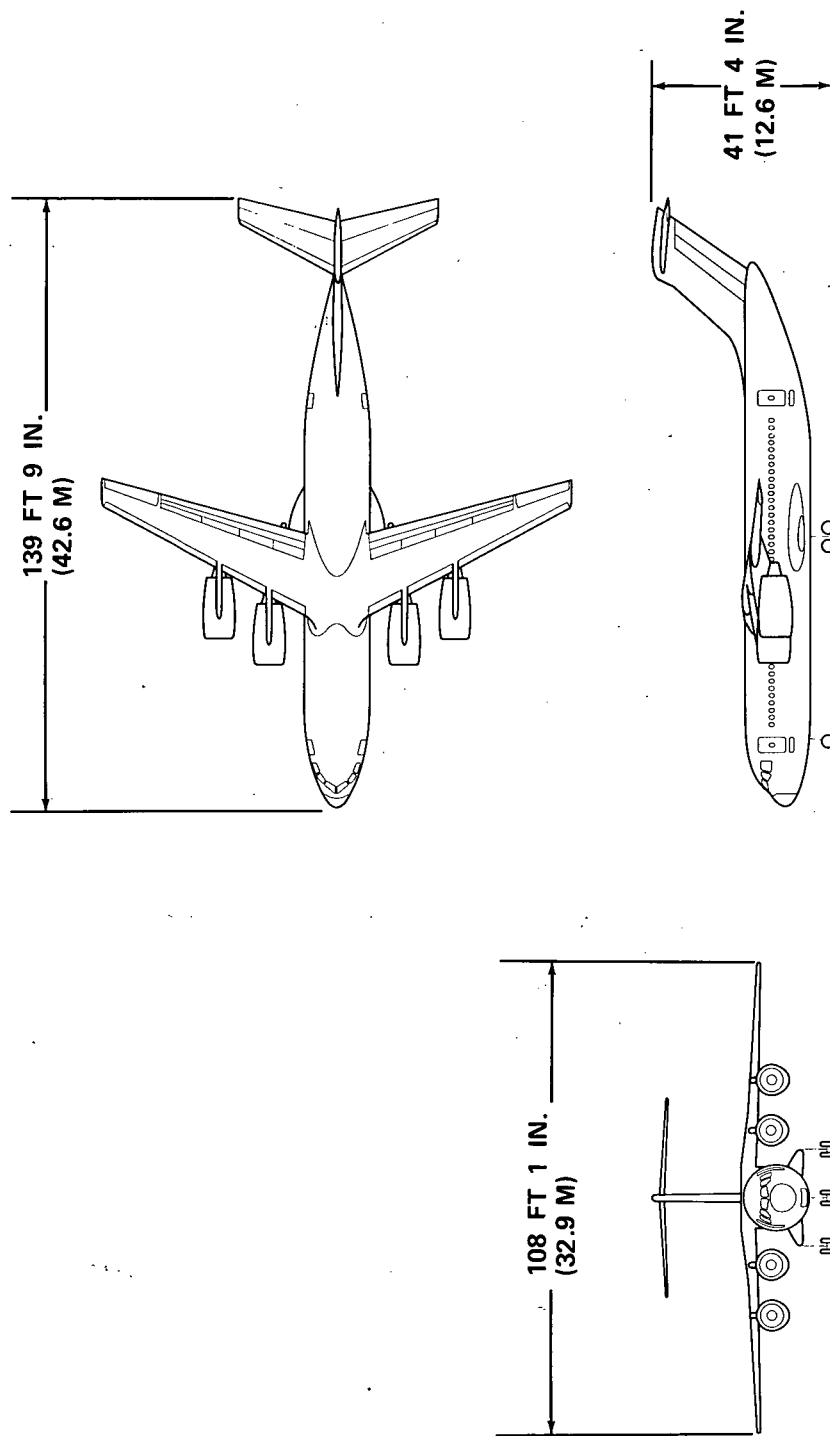
This section evaluates the potential and applicability of using takeoff and landing operational techniques to reduce the community noise impact caused by the operation of aircraft from selected airports. The aircraft used for this evaluation were the M-150-4000 aircraft from the acoustic trade study and the final design E-150-3000 aircraft from the NASA STOL Systems Study (Reference 1). Also, a version of the EBF aircraft with oversized engines was evaluated at one of the airports.

The number of people highly annoyed within the single-event 80 EPNdB contour was used as the acoustic criteria. The evaluation started with a parametric analysis of operational techniques based on a uniform population distribution. From the parametric analysis, a low-impact operational procedure was selected, for each aircraft, which resulted in the least number of people highly annoyed. The low-impact procedure was then evaluated at four airports where a minimum-impact procedure was developed at each airport by tailoring the operational techniques to minimize the number of people highly annoyed.

5.2 EBF Aircraft Characteristics

The general characteristics of the final design E-150-3000 aircraft are shown in a three-view drawing, Figure 5-1. The aircraft with oversized engines is essentially identical except for small changes in wing and tail surface areas and engine size. The engine for these EBF aircraft is the Allison PD287-3 with a takeoff bypass ratio of 17.5 and a variable-pitch fan with a pressure ratio of 1.25. Performance summary is shown in Table 5-1.

EXTERNALLY BLOWN FLAP AIRCRAFT



8/13/73

PR3-STOL-1512C

FIGURE 5-1.

Table 5-1

EBF AIRCRAFT SELECTED FOR VARIATION OF
OPERATIONAL TECHNIQUES FOR NOISE REDUCTION
PD287-3 ENGINES (1.25 FPR)

		FINAL DESIGN AIRCRAFT	10% OVER-SIZED
Payload	Passengers	150	150
Field Length	Ft. (M)	3,000 (914)	3,000 (914)
Takeoff Gross Weight	Lb. (kg)	149,000 (67,600)	151,200 (68,600)
Wing Area	Ft. ² (M ²)	1,461 (135.7)	1,400 (130.1)
Thrust per Engine	Lb. (N)	18,260 (81,220)	20,040 (89,140)
W/S	Lb/Ft ² (kg/M ²)	102 (498)	108 (527)
T/W		0.490	0.530
OEW	Lb. (kg)	102,610 (46,540)	103,900 (47,130)
M _{cr} @ 26,000 Ft. (7,925 M)		0.69	0.71
D.O.C. @ 575 St.Mi. (926 KM)	¢/ASSM (¢/ASKM)	2.075 (1.289)	2.082 (1.293)
EPNL @ 500-Ft. Sideline (152 m)	EPNdB	97.1	96.9

5.3 MF Aircraft Characteristics

The selection of the mechanical-flap STOL aircraft for the operational noise reduction techniques study was based on the results of the Acoustic Trade Study (see Section 4.0). In this study, the 1.57 FPR engine with acoustic wall treatment was found to produce the lowest direct operating costs, and sideline noise levels only 2 EPNdB higher than the quietest engine examined. This engine has a fixed-pitch fan and a bypass ratio of 5.9.

Initially both the M-150-3000 and M-150-4000 aircraft with two 1.57 FPR engines were selected for examination. Standard flight profiles and noise contours were calculated for both aircraft as described in Section 5.4. Based on these contours, there was no appreciable difference in community noise impact (based on uniform population distribution) for the two aircraft. Selection of the 4000-foot (1219 m) field length aircraft for study at the specific airports was made on the basis of its lower DOC, 1.74 ¢/ASSM (1.08 ¢/ASKM) as compared to 2.06 ¢/ASSM (1.28 ¢/ASKM) for the 3000-foot (914 m) field length aircraft, and its lower mission fuel consumption. A brief summary comparing the characteristics of the two aircraft is presented in Table 5-2. A three-view drawing of the selected aircraft is shown in Figure 5-2.

5.4 Aircraft Acoustics Characteristics

5.4.1 Evaluation Procedures - The evaluation of operational techniques for noise reduction was performed on the basis of aircraft noise contours and community noise impact. Contours of 100, 95, 90, 85, and 80 EPNdB were generated using the Douglas-developed Aircraft Noise Contour/Community Noise Impact Evaluation (A1FA) digital computer program in conjunction with a Gerber plotter. The computer inputs required for noise contours include noise data,

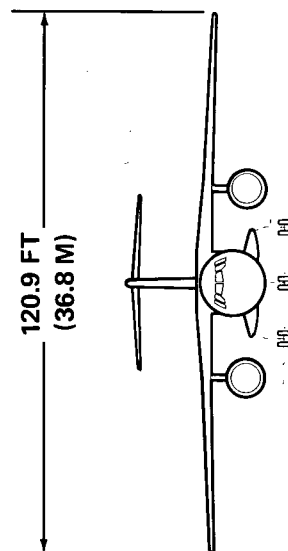
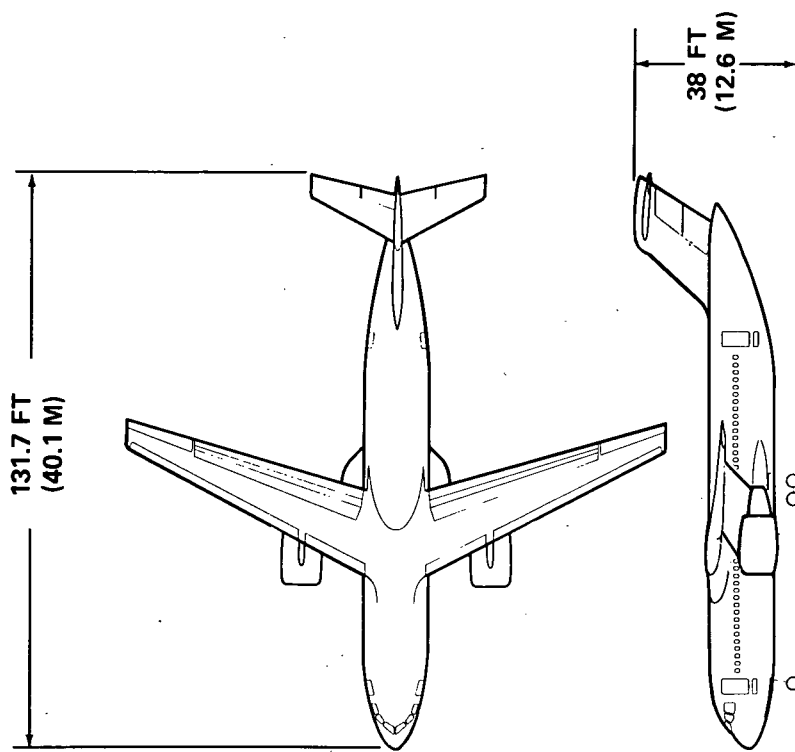
Table 5-2

CANDIDATE MECHANICAL-FLAP AIRCRAFT
OPERATIONAL TECHNIQUES FOR NOISE REDUCTION
1.57 FPR ENGINES WITH ACOUSTIC WALL TREATMENT

			SELECTED AIRCRAFT
Payload	Passengers	150	150
Field Length	Ft. (M)	3,000 (914)	4,000 (1,219)
Takeoff Gross Weight	Lb. (kg)	172,300 (78,150)	143,600 (65,140)
Wing Area	Ft. ² (M ²)	2,848 (264.6)	1,679 (156.0)
Thrust per Engine	Lb. (N)	30,680 (136,470)	26,870 (119,520)
W/S	Lb/Ft ² (kg/M ²)	60.5 (295.4)	85.5 (417.4)
T/W		0.356	0.374
OEW	Lb. (kg)	122,940 (55,770)	97,550 (44,250)
M _{cr} @ 30,000 Ft. (9144 M)		0.74	0.77
D.O.C. @ 575 St.Mi. (926 KM)	¢/ASSM (¢/ASKM)	2.06 (1.28)	1.74 (1.08)
EPNL @ 500-Ft. Sideline (152 m)	EPNdB	101.0	100.5

GENERAL ARRANGEMENT

M-150-4000 — TWO 5.9/1.57 ENGINES



PR4-STOL-2403

FIGURE 5-2

in the form of EPNL as a function of slant distance, and flight path and performance data such as the aircraft position, airspeed, flap setting, and engine operating parameters.

Using this program, the aircraft noise level, in terms of EPNL, corresponding to a takeoff and approach flight path was calculated at each 500-foot (152 m) sideline interval, relative to the airport runway centerline, to form a rectangular grid of EPNL values. Contours of equal EPNL were calculated by interpolation within the grid. The EPNL at each grid point was determined by finding the minimum distance to the flight path and relating the noise level to the aircraft operating conditions at that point on the flight path. EPNL adjustments were made for airspeed, based on a 10 log (ratio of the actual airspeed to the reference airspeed) relationship, and ground attenuation (EGA) and fuselage shielding based on SAE ARP 1114.

The evaluation of community noise impact required additional information in the form of population density data at each airport. The population density data was formulated as the average number of people at each 500-foot (152 m) sideline interval relative to a rectangular coordinate system which had its origin at the airport reference point. The community noise impact was calculated by a transformation of the EPNL coordinate system into the population density coordinate system, interpolation to determine the EPNL at each population (P) grid point, calculating the fraction (K) of people highly annoyed, and calculating the sum of the product of K and P for all grid points within the 80 EPNdB contour. The relationship of the fraction of people highly annoyed to EPNL assumes zero annoyance for a noise level below or equal to 80 EPNdB. For noise levels greater than 80 EPNdB the relationship is linear and passes through 40 percent highly annoyed at

100 EPNdB. These relationships were developed from the annoyance chart of Reference 2, which is shown in Figure 5-3. It should be pointed out that the data shown in Figure 5-3 are highly subjective, and a more detailed analysis at a specific airport would require additional information about the annoyance levels of the surrounding community.

5.4.2 EPNL vs Distance Plots - Plots of EPNL as a function of slant distance were calculated in accordance with the procedures discussed in Reference 4 Appendix C-1. A plot for the M-150-4000 aircraft is shown in Figure 5-4. Engine noise and propulsive-lift system noise for the E-150-3000 aircraft were calculated independently and then summed to arrive at the total aircraft noise.

5.4.3 Standard Flight Profiles - Standard takeoff and landing procedures were defined as a starting point for the parametric study of operational techniques for noise reduction. The parametric variations in this study are based on perturbations from these standard flight procedures. It was desired that the standard flight procedures be representative of normal commercial operations.

Takeoff - The standard takeoff flight profile for the E-150-3000 aircraft is shown in Figure 5-5. The standard climbout maneuver consists of the following segments:

1. Takeoff - Normal STOL takeoff; gear retraction assumed to be complete 10 seconds after liftoff.
2. Accelerate - Accelerate to V_{CLIMB} while maintaining constant aircraft attitude.
3. Flap Retraction - Retract flaps from takeoff position to zero flap at a rate of 3 degrees per second (0.05 rad/sec) commencing at 400 feet (122 m). Slats are left extended during the climb to provide high maneuver margins.
4. Climb - Climb at constant speed to a height of 1500 feet (457 m).

COMMUNITY RESPONSE TO AIRCRAFT NOISE

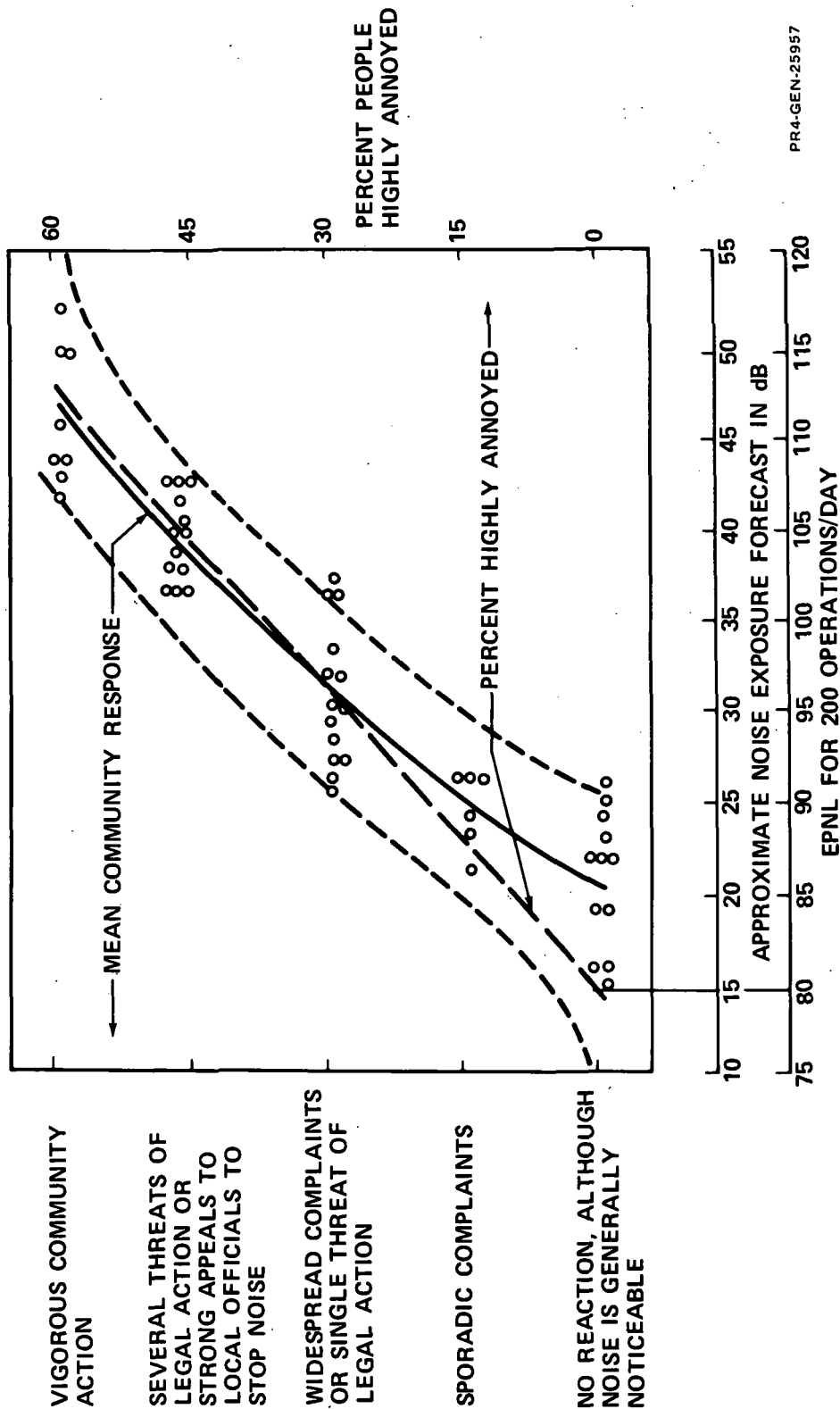
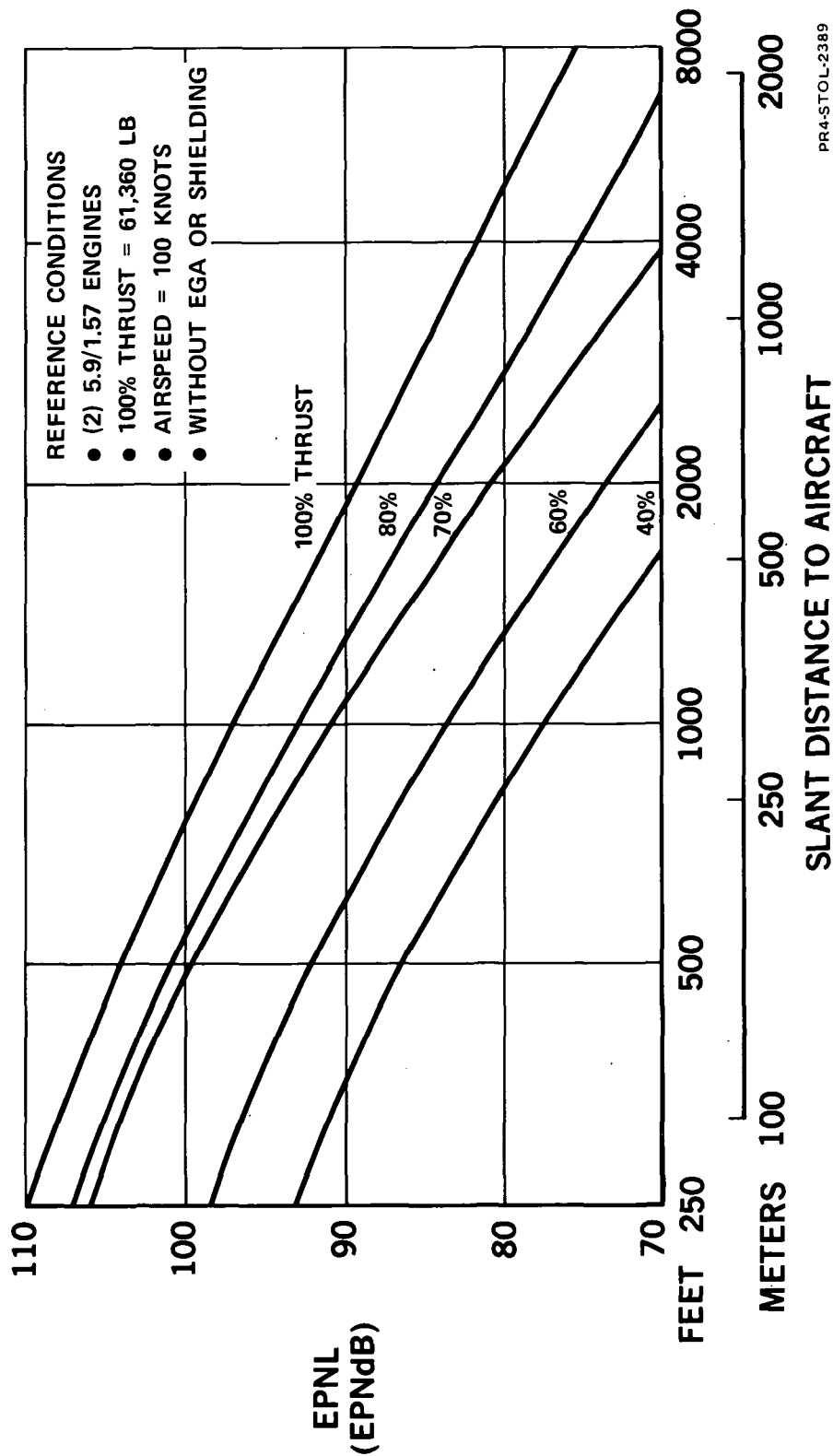


FIGURE 5-3

PR4-GEN-25957

EPNL vs DISTANCE

MECHANICAL FLAP 150 PASSENGERS 3000 FT (914 m) FIELD LENGTH



PR4-STOL-2389

FIGURE 5-4

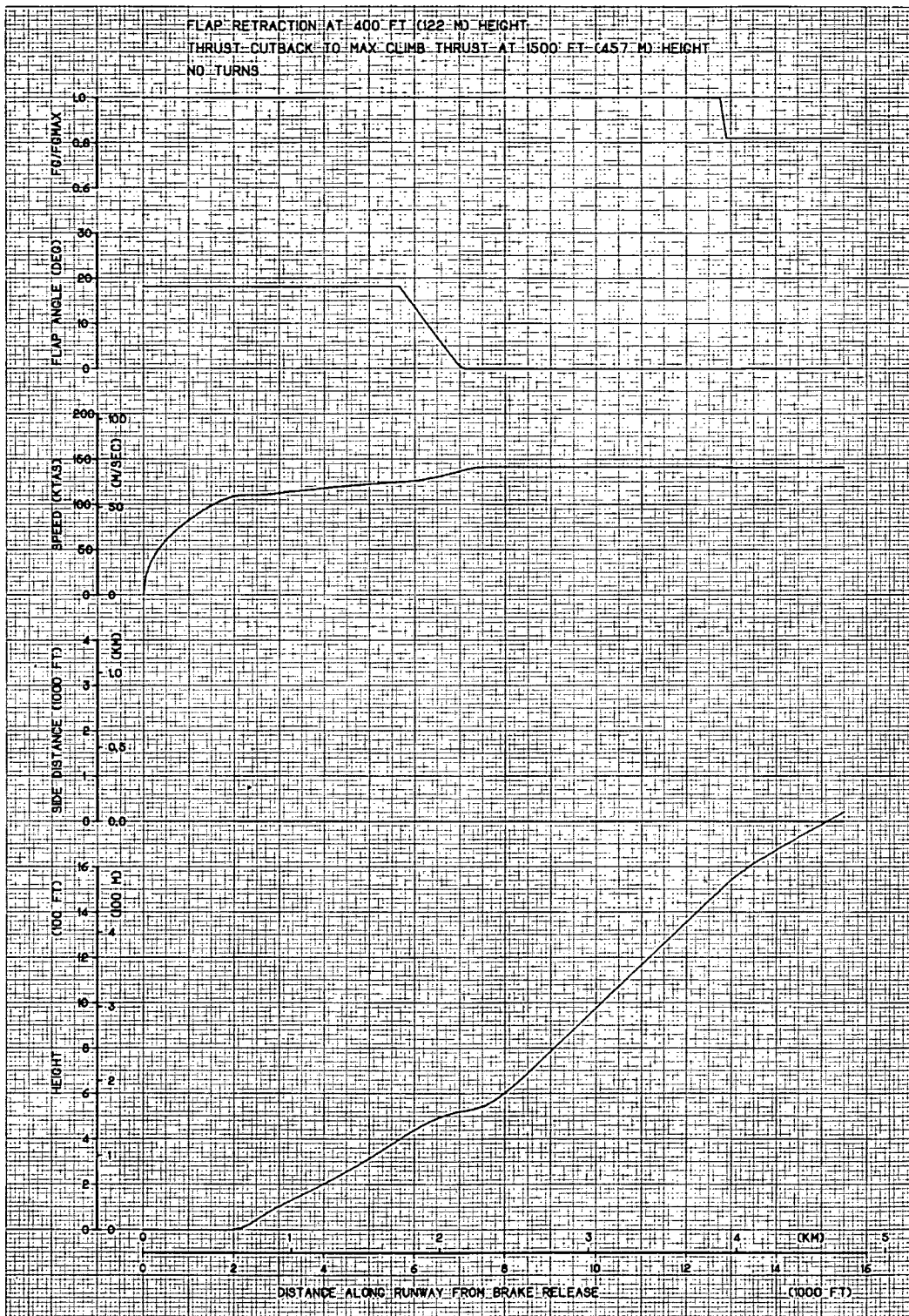


FIGURE 5-5. STANDARD TAKEOFF PROFILE E-150-3000 AIRCRAFT

5. Thrust Cutback - Starting at 1500 feet (457 m), reduce thrust at a rate of 30 percent per second from takeoff thrust to climb thrust.
6. Climb at constant speed with climb thrust.

Landing - The standard approach flight procedure is a decelerating approach with a constant glide slope. Glide slope angle was selected to provide a sink rate of 900 fpm (4.6 m/sec) at the threshold height with final approach speed. This results in path angles of approximately 5.4 degrees (0.094 rad) for a 3000-foot (914 m) field length aircraft and 4.5 degrees (0.079 rad) for a 4000-foot (1219 m) field length aircraft. Approach flap is used down to a height of 1000 foot (305 m) at which point flaps are extended at a rate of 3 degrees per second (0.05 rad/sec) to the landing flap setting. As the threshold is approached, thrust is increased as required to maintain the glide slope and to stabilize approach speed.

5.4.4 Standard Noise Contours - Based on the standard takeoff and approach flight paths defined in Section 5.4.3, standard noise contours of 100, 95, 90, 85 and 80 EPNdB were generated for the M-150-3000, M-150-4000, and E-150-3000 aircraft. The noise contours for the E-150-3000 aircraft are shown in Figure 5-6. In each case, the size of the takeoff contours is much larger than the size of the landing contours. This would seem to imply that, for these aircraft, takeoff operational techniques would offer the most potential for reducing community noise impact.

5.5 Parametric Study of Operational Techniques

5.5.1 Objectives - A parametric study of takeoff and landing operational techniques for noise reduction was conducted to narrow down the number of techniques to be evaluated at each airport. The parametric study resulted in

NASA AMES CONTRACT -- PARAMETRIC STUDY OF STOL
SHORT-HAUL TRANSPORT ENGINE CYCLES AND OPERATIONAL
TECHNIQUES TO MINIMIZE COMMUNITY NOISE IMPACT

E-150-3000 STANDARD TAKEOFF AND STANDARD APPROACH

EPNL	AREA (SQ MI)	AREA (SQ KM)
80.0	3.19	8.27
85.0	1.71	4.43
90.0	0.92	2.38
95.0	0.44	1.14
100.0	0.18	0.45

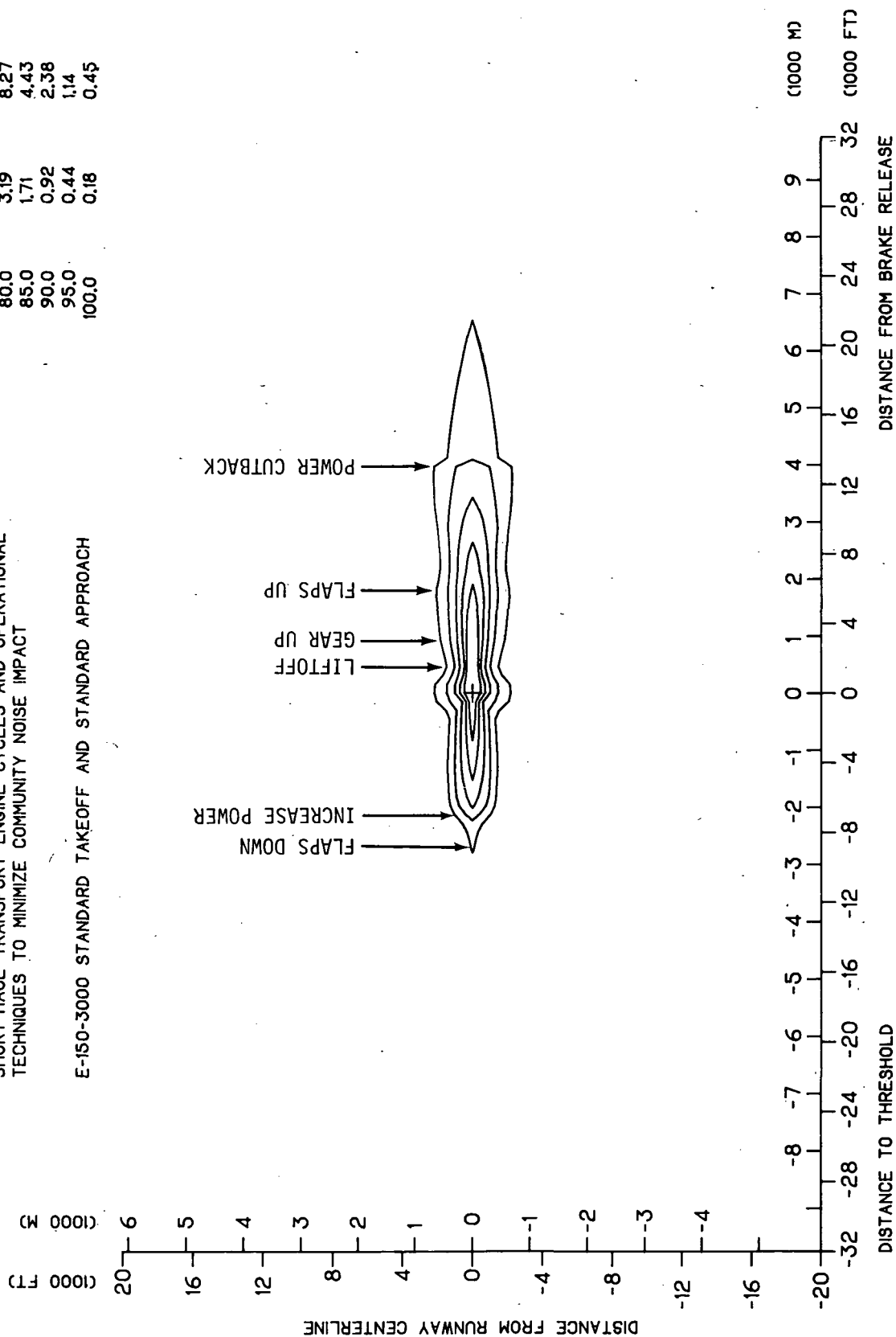


FIGURE 5-6.

the selection of a takeoff and landing operational procedure, for each aircraft, which would produce the lowest noise impact based on a uniform population density. These low-impact procedures provide a starting point for determining the best operational procedures to use at each airport to produce the minimum community noise impact.

5.5.2 Evaluation Procedure - Takeoff and landing operational techniques were evaluated on a noise impact basis assuming a uniform population density. The evaluation started with the standard takeoff and approach procedure for each aircraft and the effect of varying each operational parameter was evaluated independently. The resulting change in noise impact was compared to the noise impact produced by the standard takeoff and approach procedure.

The philosophy taken concerning the variations of the takeoff and landing flight profiles was that the flight procedures should be compatible with both VFR and IFR operations. On this basis, the following operational constraints were imposed:

Takeoff

1. No turns or thrust cutbacks were made below a height of 500 feet (152 m).
2. Amount of thrust cutback limited so that all-engine climb gradient $\geq 4\%$; one-engine-out climb gradient $\geq 0\%$.

The all-engines-operating 4-percent gradient requirement was found to be critical for the four-engine EBF aircraft and the zero gradient with one engine failed was critical for the MF twin-engine aircraft.

3. Combination maneuvers were avoided, i.e., changing thrust level during a turn or changing flap setting during a turn.

Landing

1. At a height of 500 feet (152 m) the aircraft should be essentially stabilized in the final landing configuration. Therefore, no changes in flap angle, glide slope or turns were made below a height of 500 feet (152 m).
2. The final approach descent rate was limited to a maximum of 1000 ft/min (5.1 m/sec).

5.5.3 Takeoff Techniques - Takeoff procedures incorporating variations in flap retraction height, flap retraction rate, thrust cutback height and thrust cutback amount were evaluated. The results show, for the EBF aircraft, that flap retraction should occur as soon as practical after liftoff in order to minimize propulsive-lift system noise. The noise impact for the MF aircraft was not particularly sensitive to flap retraction height or rate. Early flap retraction was found to give a slight reduction in noise impact. Flap retraction rate should be kept low to minimize hydraulic power requirements. A rate of 3 deg/sec (0.05 rad/sec) was found to be the lowest rate which did not increase noise impact. For both aircraft, thrust should be cut back to the lowest level consistent with safe aircraft operation. Selection of thrust cutback height is based on a tradeoff between minimizing noise close to or far from the airport. The particular value selected is strongly influenced by the particular aircraft performance and noise generation characteristics. From these results, a low-impact operational procedure which produced the lowest noise impact based on a uniform population distribution was developed for each aircraft. The selected low-impact takeoff operational procedure for each aircraft is defined on the following page.

		<u>E-150-3000</u>	<u>M-150-4000</u>
Flap Retraction Height	Ft(m)	200 (70)	250 (76)
Flap Retraction Rate	Deg/Sec(Rad/Sec)	3 (0.0525)	3 (0.0525)
Thrust Cutback Height	Ft(m)	1000 (305)	750 (229)
Thrust Cutback Power	%	64	66

5.5.4 Approach Techniques - The small size of the noise contours for the standard approach procedure was a limiting factor in evaluating potential approach operational techniques for noise reduction. The techniques evaluated were limited to two-segment glide slopes and decelerating approaches.

The use of a two-segment glide slope did not prove to be useful for noise levels above 80 EPNdB because of the low aircraft noise levels. The approach noise contours for both aircraft were fully developed within the second segment of the approach, so the first or steep glide slope segment had no effect on the noise contours. The first- and second-segment glide slope intersection height was chosen to be 750 feet (229 m) for the two-segment technique in order that stabilization be achieved prior to reaching a height of 500 feet (152 m).

As descent rate increases there is a reduction in noise impact. The descent rate chosen for the low-impact approach procedure was 1000 ft/min (5.1 m/sec). The landing flap extension rate was held to a minimum to permit a low power setting while decelerating. The selected low-impact approach procedure for each aircraft is defined as follows:

		<u>E-150-3000</u>	<u>M-150-4000</u>
Descent Rate	Ft/Min (m/sec)	1000 (5.1)	1000 (5.1)
Flap Extension Rate	Deg/Sec (rad/sec)	1 (0.0175)	1 (0.0175)
Approach Power		Idle	Idle

5.6 Community Noise Impact Evaluation

The potential for applying the previously described noise abatement operational techniques to a number of representative existing short-haul airports is demonstrated in this section. The four airports selected for this evaluation are well known airports with recognized noise problems. The representative sample includes primary CTOL, secondary CTOL, general aviation and military joint-use airports, each with different community characteristics and noise problems.

5.6.1 Objectives - The primary objective of the airport noise evaluation phase of the study was to demonstrate that aircraft noise impact can be significantly reduced by flight operational techniques. A secondary objective was the development of an effective methodology or tool for assessing aircraft noise impact on the airport and adjacent community.

5.6.2 Evaluation Criteria and Procedures - The criterion used for evaluating the aircraft noise impact at a specific airport was the total number of people highly annoyed within the 80 EPNdB contour during a combined takeoff and landing operation. Noise contour area by itself is not an adequate measure of aircraft community noise impact unless the community has a uniform population density. This is rarely the case. Contour areas can be used to compare noise differences between aircraft types and/or operational procedures; however, it is believed essential when measuring community noise impact to determine the number of persons exposed, as well as the degree of annoyance. The methodology which considers these elements for determining the number of people annoyed has been previously described in Section 5.4.1.

Many operational procedures were evaluated at each airport for each aircraft type. The evaluation began assuming a standard operational procedure developed on the basis of estimated normal operating procedures

for short-haul aircraft.

As a result of the parametric study of flight operational techniques of the EBF and MF aircraft a low-impact operational procedure was developed for each aircraft type. The low-impact procedure incorporates the landing and takeoff operational techniques which provided the lowest noise impact assuming a uniform population distribution.

By superimposing the EPNL contours produced by the low-impact operational procedure on a standard 7.5 minute U.S.G.S. topographical map showing population distribution it was possible to optimize or "fine-tune" the low-impact operational procedure and resultant noise contour to the specific airport configuration by varying flight techniques. Primary operational variations were power cutbacks and turns. The contour was shaped by varying the level of power cutback, cutback altitude, and turn amount and altitude. Turns were made where appropriate to follow waterways, railroads, etc., or to avoid highly populated and noise sensitive areas. Optimization was not feasible for the landing operational procedure since the area of the noise contours using the low-impact decelerating approach technique already was minimal.

The population data input into the Douglas ALFA computer program was derived from the 1970 census tract and block statistics reports issued by the U.S. Bureau of the Census. In some instances it was found necessary to adjust the block data to reflect areas of zero population (e.g., rivers, lakes, parks, cemeteries, etc.). The population density was calculated for each 500 feet (152 m) interval grid point over an area of approximately 130 square miles (337 sq. km.).

5.6.3 Airport Selection - A national network of short-haul airports was developed under the previous NASA Short-Haul Systems Study conducted by the Douglas Aircraft Company and reported in Reference 1. A total of over 200 airports were surveyed in the study and twelve representative airports were selected for detailed community analysis. The current study selected four of the twelve for evaluation of noise reduction flight operational techniques. The NASA Systems Study contained a detailed discussion of the reasons for selection of the twelve airports. Primary criteria were airport type, activity level, geographical location, adjacent land use, and relative importance to a national short-haul transportation system. The four airports evaluated in the current study were chosen as being most representative with respect to operational noise problems and land use characteristics. All currently are experiencing aircraft noise problems ranging from moderate to severe. The four airports and their key characteristics are shown below:

<u>Code</u>	<u>Airport</u>	<u>NASP Class</u>	<u>Operational Class</u>	<u>Land Use Category</u>
BED	Hanscom Field Runway 5	S-2	G.A./Military	Residential/Military
DCA	Washington National Runway 18/36	P-2	Air Carrier/G.A.	Recreational/Industrial
SNA	Orange County Runway 19R	S-1	Air Carrier/G.A.	Residential/Commercial
MDW	Chicago Midway Runway 22L Runway 31L	S-2	Air Carrier/G.A.	Residential/Industrial

5.6.4 Community Noise Impact - Aircraft characteristics and noise reduction flight operational techniques applicable to the E-150-3000 and M-150-4000 airplanes were previously discussed in Sections 5.2 and 5.5. The results of

applying these techniques at the four study airports are shown in Figures 5-7 through 5-17. The low-impact flight procedures and resultant noise contours were developed from the operational parametric analysis which assumed a uniform population distribution. The minimum-impact procedure was developed by "fine-tuning" the flight procedures to specific airport and community characteristics which differ at each airport.

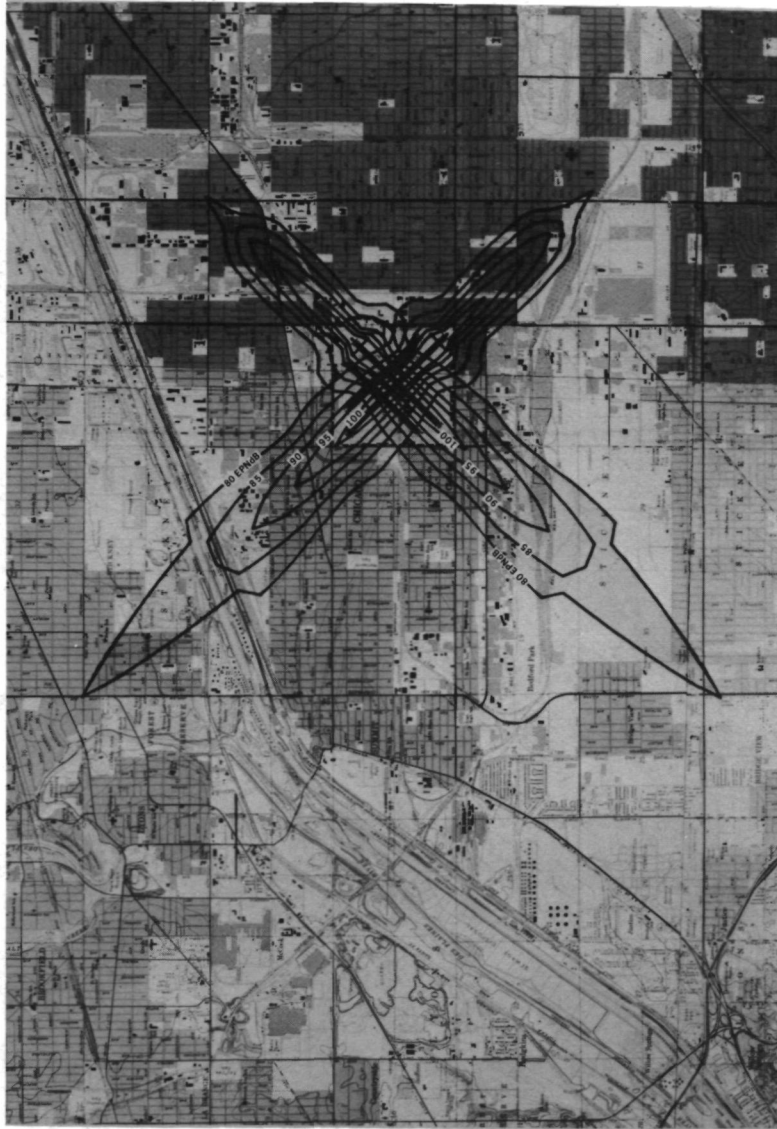
Single-event noise contours for 100, 95, 90, 85, and 80 EPNdB levels were developed for each flight procedure. The NASA Systems Study (Reference 1) did not evaluate noise levels below 90 EPNdB. It was found during the current study that a significant number of people are affected within the contour bands between 80 and 90 EPNdB which justifies investigation of the lower noise level. The single-event noise level of 80 EPNdB for the two aircraft analyzed translates to approximately 67 dBA which is below the ambient noise level of most communities.

The shape of the noise footprints of the M-150-4000 differ from those of the E-150-3000 airplane due to differences in design sideline noise levels and aircraft performance characteristics of the two aircraft types. The approach and takeoff lobes of the M-150-4000 footprints are slightly wider than the E-150-3000 due to the higher design sideline noise level. The takeoff lobes are shorter because of the greater climb gradient of the MF airplane.

5.6.5 Summary of Results - Results of the community noise evaluation for the E-150-3000 and the M-150-4000 airplanes are summarized in Tables 5-3 through 5-17. Tables 5-3 through 5-14 show for each EPNL contour, the area, the total population, and the number of persons highly annoyed for the three operational procedures which were investigated at the four airports.

COMMUNITY NOISE IMPACT

STANDARD FLIGHT PROCEDURE — MIDWAY RWYS 22L, 31L
E-150-3000 AIRPLANE



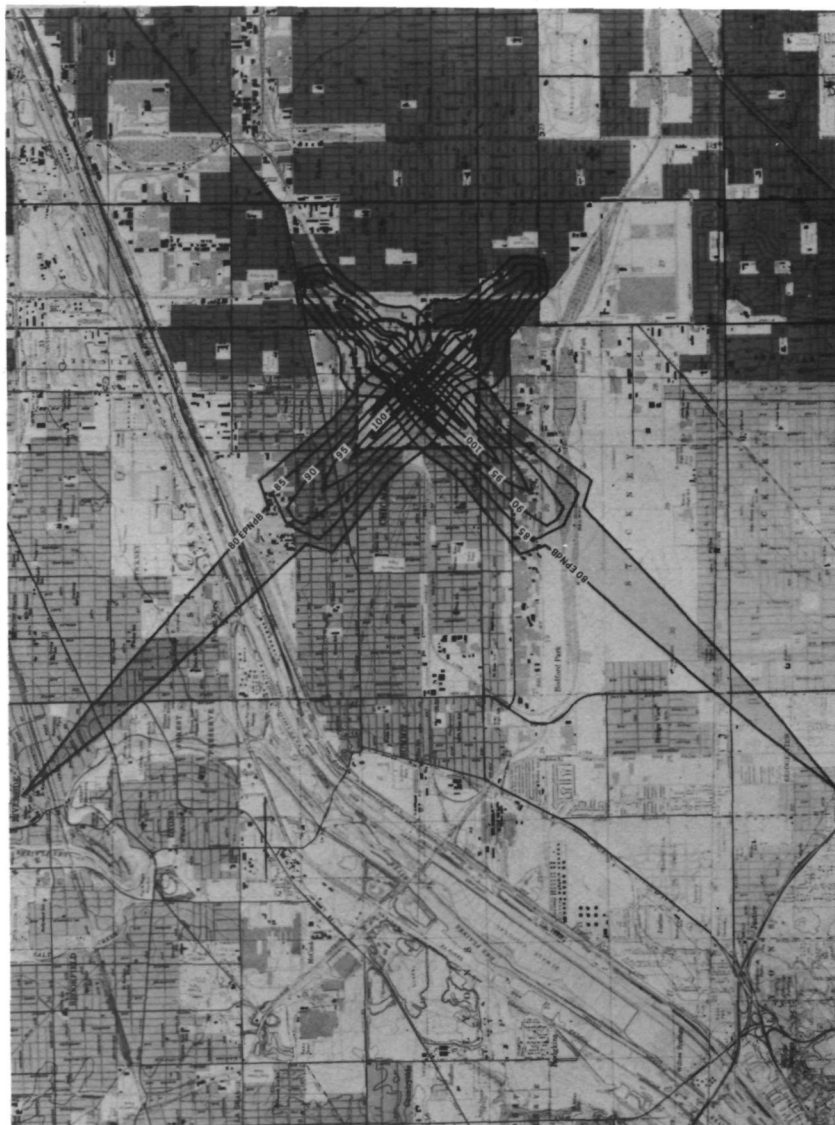
RWY 22L — PERSONS EXPOSED 11,960 PERSONS HIGHLY ANNOYED 1,819
RWY 31L — PERSONS EXPOSED 15,559 PERSONS HIGHLY ANNOYED 2,168

PR4-STOL-2362

FIGURE 5-7.

COMMUNITY NOISE IMPACT

LOW-IMPACT PROCEDURE — MIDWAY RWYS 22L, 31L E-150-3000 AIRPLANE



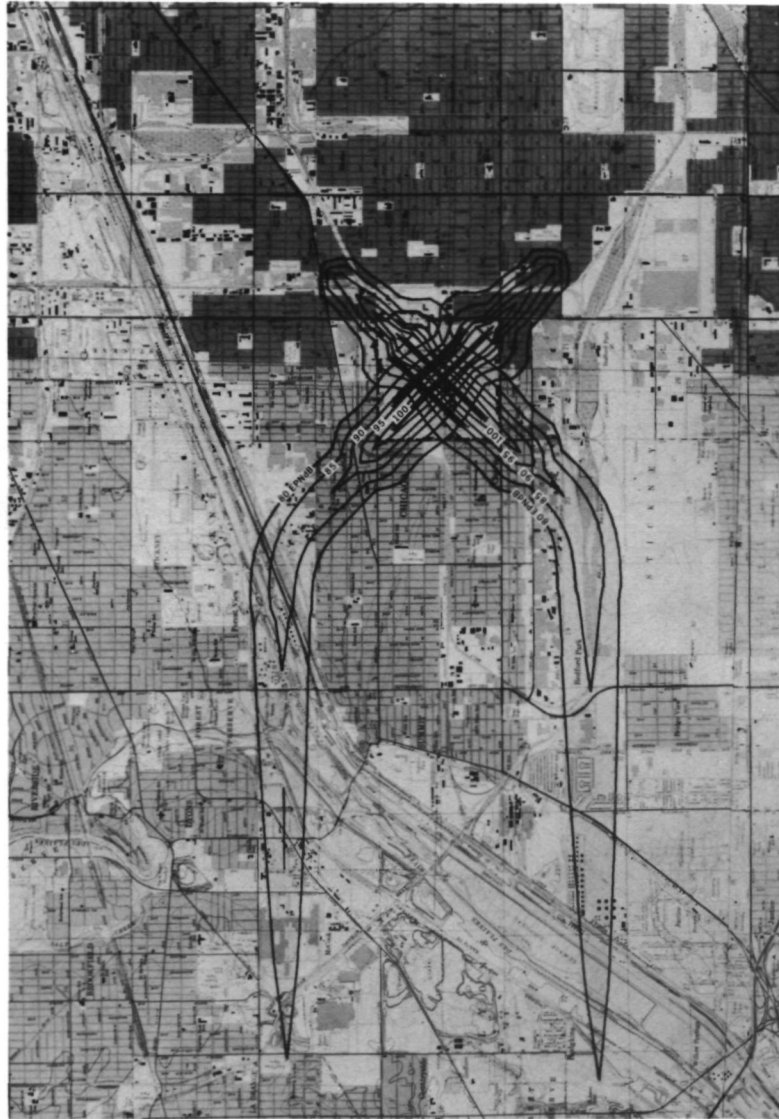
RWY 22L — PERSONS EXPOSED 8,018 PERSONS HIGHLY ANNOYED 1,117
RWY 31L — PERSONS EXPOSED 12,780 PERSONS HIGHLY ANNOYED 1,619

PR4-STOL-2363

FIGURE 5-8.

COMMUNITY NOISE IMPACT

MINIMUM IMPACT PROCEDURE — MIDWAY RWYS 22L, 31L E-150-3000 AIRPLANE



RWY 22L — PERSONS EXPOSED 6,895 PERSONS HIGHLY ANNOYED 997
 RWY 31L — PERSONS EXPOSED 9,956 PERSONS HIGHLY ANNOYED 1,322

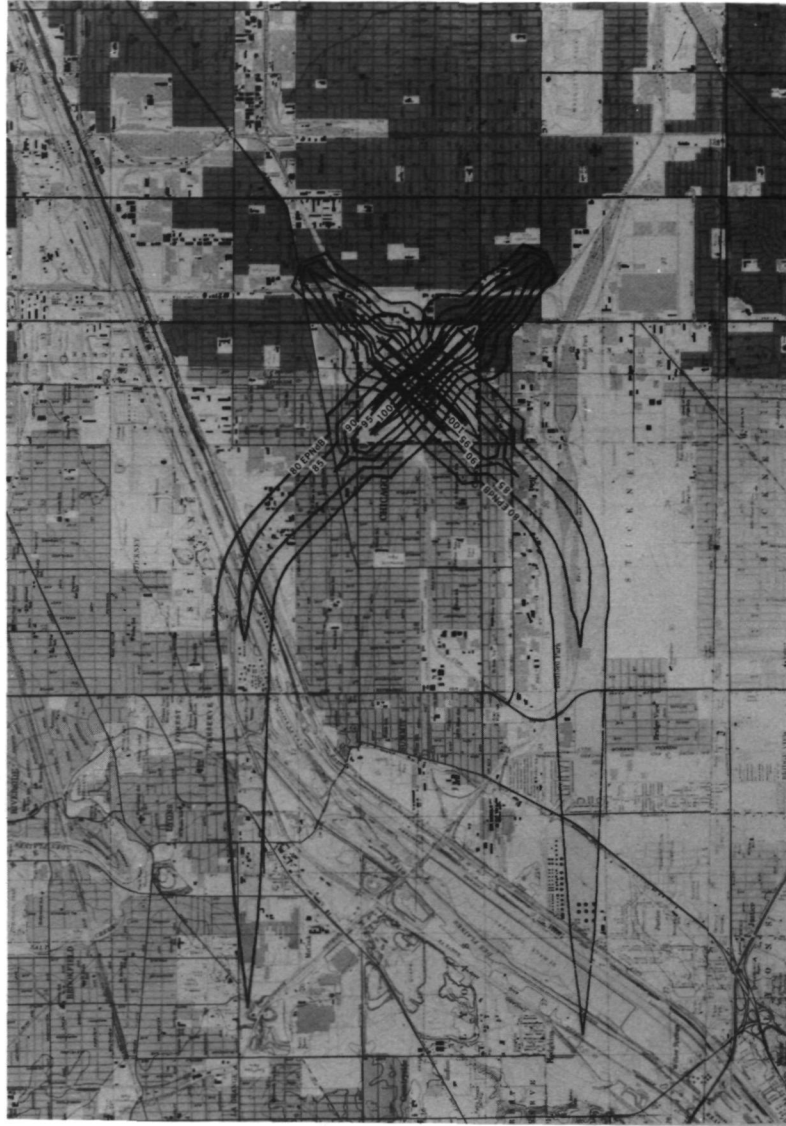
PR4-STOL-2364

FIGURE 5-9.

COMMUNITY NOISE IMPACT

MINIMUM IMPACT PROCEDURE — MIDWAY RWYS 22L, 31L

E-150-3000 AIRPLANE WITH 10% OVERSIZED ENGINES



RWY 22L — PERSONS EXPOSED	6,940	PERSONS HIGHLY ANNOYED	903
RWY 31L — PERSONS EXPOSED	10,245	PERSONS HIGHLY ANNOYED	1,236

PR4-STOL-2366

FIGURE 5-10.

COMMUNITY NOISE IMPACT

MINIMUM IMPACT PROCEDURE — HANSCOM FIELD RWY 5

E-150-3000 AIRPLANE



PERSONS EXPOSED 2,079

PERSONS HIGHLY ANNOYED 188

FIGURE 5-11.

PR4-STOL-2353

COMMUNITY NOISE IMPACT

MINIMUM IMPACT PROCEDURE — ORANGE COUNTY RWY 19R
E-150-3000 AIRPLANE



PERSONS EXPOSED 3,067 PERSONS HIGHLY ANNOYED 282

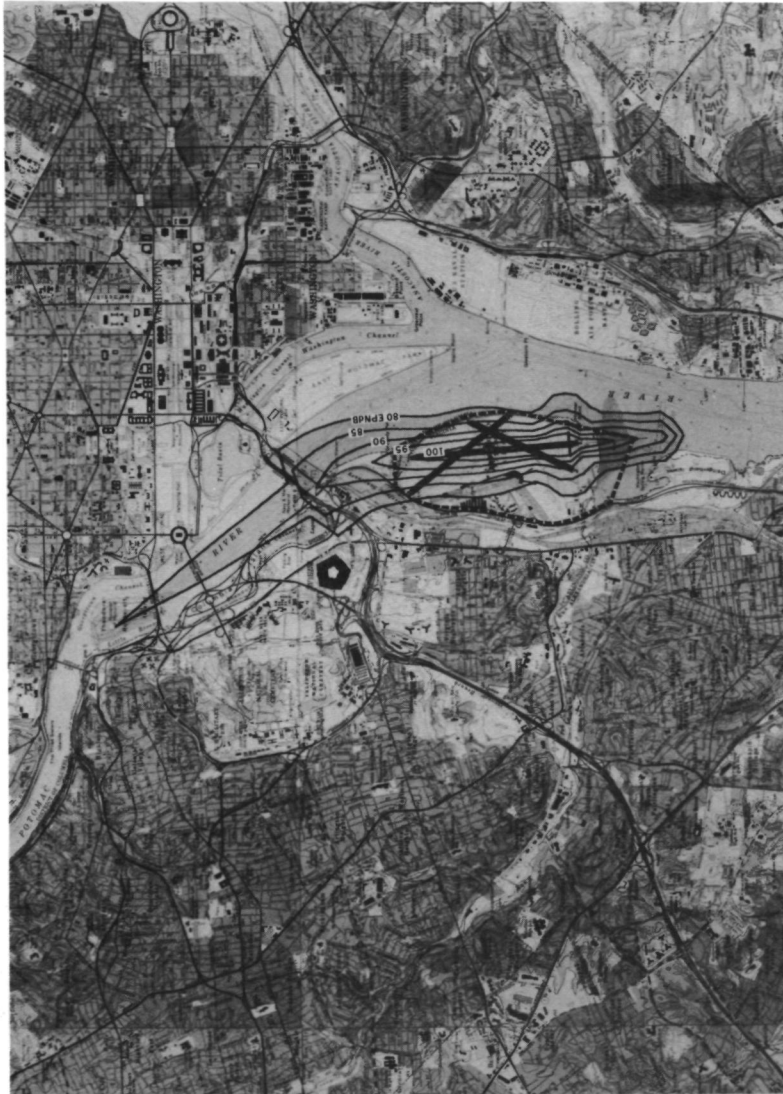
FIGURE 5-12.

PR4-STOL-2360

COMMUNITY NOISE IMPACT

MINIMUM IMPACT PROCEDURE — WASHINGTON NATIONAL RWY 36

E-150-3000 AIRPLANE



PERSONS EXPOSED 0 PERSONS HIGHLY ANNOYED 0

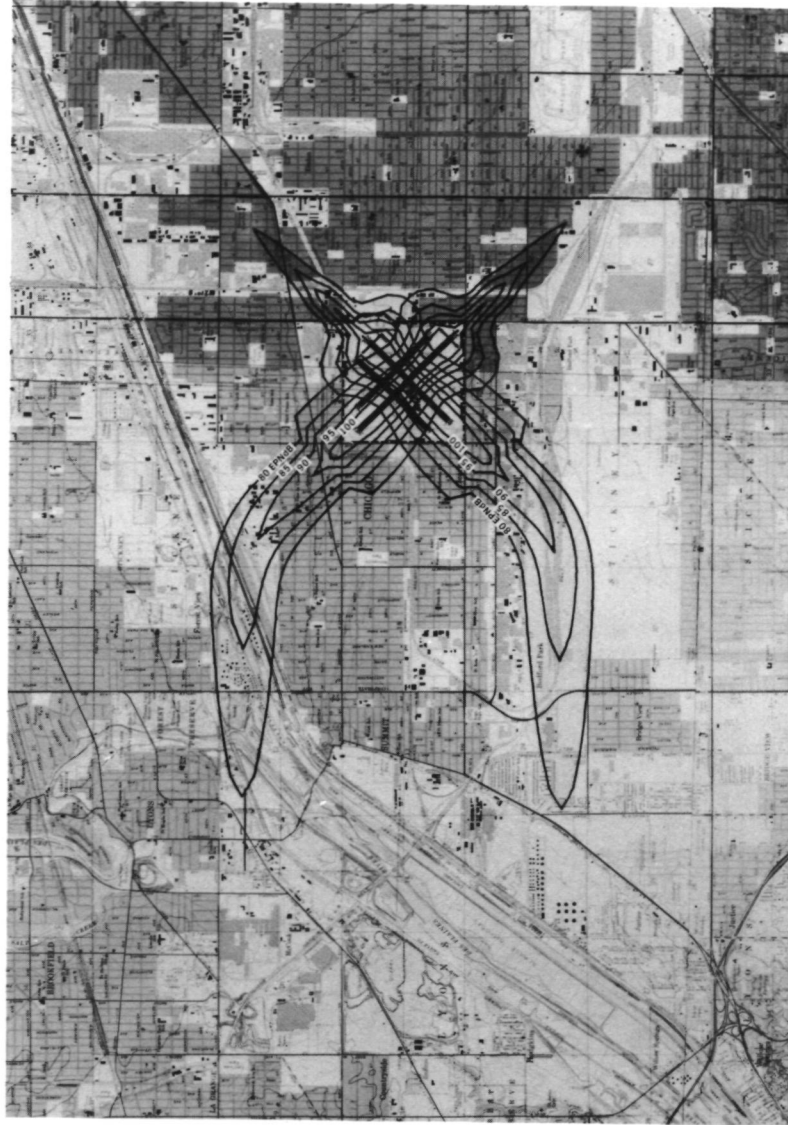
PR4-STOL-2356

FIGURE 5-13.

COMMUNITY NOISE IMPACT

MINIMUM-IMPACT PROCEDURE — MIDWAY RWYS 22L, 31L

M-150-4000 AIRPLANE



	PERSONS EXPOSED	PERSONS HIGHLY ANNOYED
RWY 22L —	8,247	1,178
RWY 31L —	10,554	1,549

PR4-STOL-2379

FIGURE 5-14.

COMMUNITY NOISE IMPACT

MINIMUM IMPACT PROCEDURE — HANSCOM FIELD RWY 5

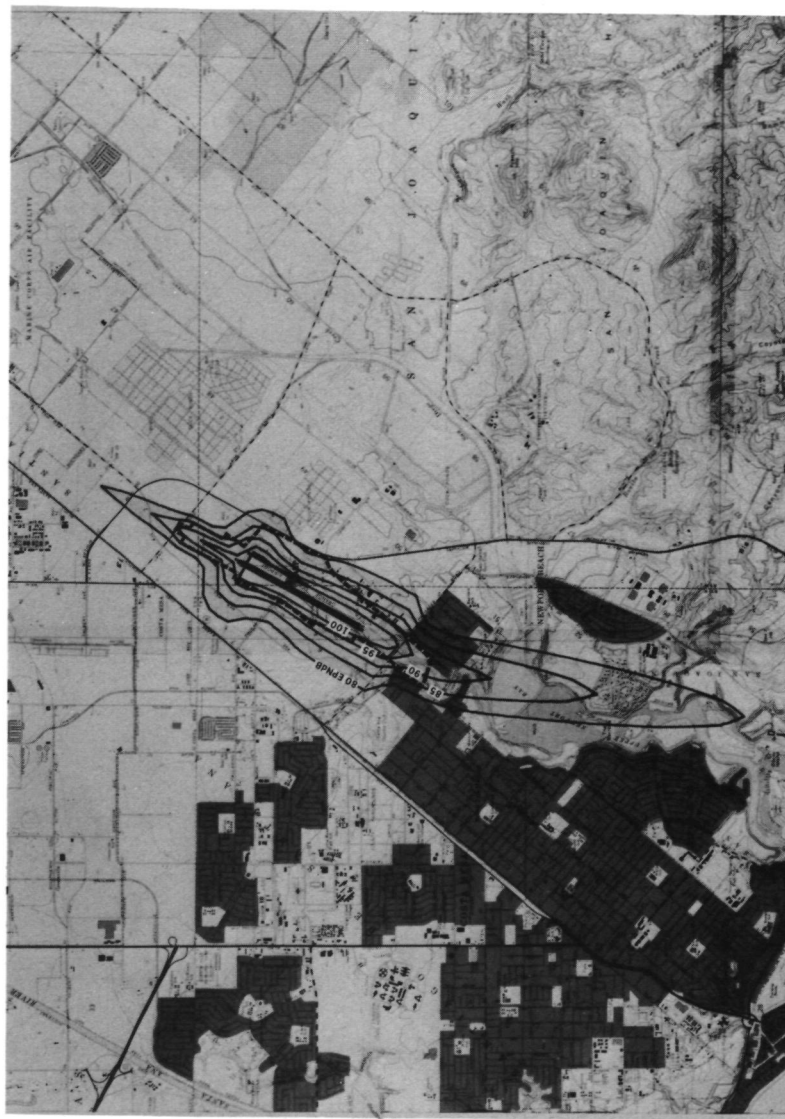
M-150-4000 AIRPLANE



PERSONS EXPOSED 2,136 PERSONS HIGHLY ANNOYED 243

FIGURE 5-15. PR4-STOL-2369

COMMUNITY NOISE IMPACT
MINIMUM IMPACT PROCEDURE — ORANGE COUNTY RWY 19R
M-150-4000 AIRPLANE



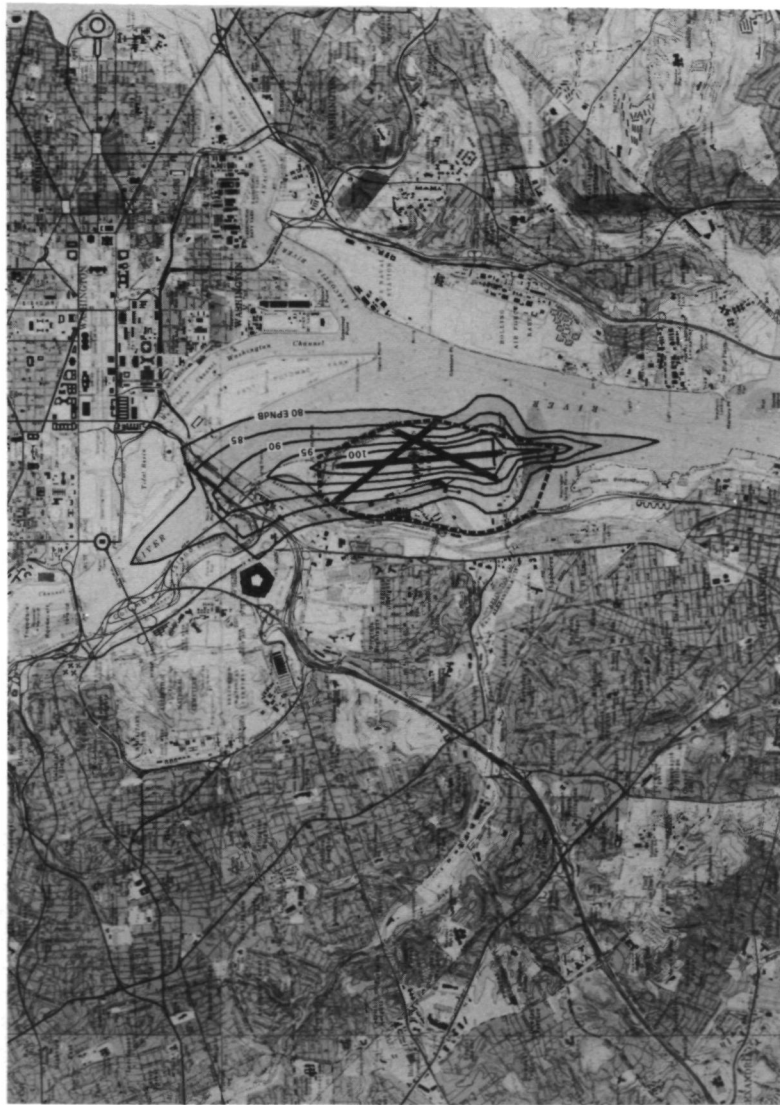
PERSONS EXPOSED 2,516 **PERSONS HIGHLY ANNOYED 364**

FIGURE 5-16.

PR4-STOL-2376

COMMUNITY NOISE IMPACT

MINIMUM IMPACT PROCEDURE — WASHINGTON NATIONAL RWY 36
M-150-4000 AIRPLANE



PERSONS EXPOSED 0

PERSONS HIGHLY ANNOYED 0

FIGURE 5-17.

PR4-STOL-2372

TABLE 5-3
NOISE IMPACT SUMMARY - E.150.3000 AIRPLANE
HANSCOM FIELD - RUNWAY 5

EPNL Contour	STANDARD PROCEDURE				LOW-IMPACT PROCEDURE				MINIMUM-IMPACT PROCEDURE			
	Contour Area		Population		Contour Area		Population		Contour Area		Population	
	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed
100	0.18	0.45	56	27	0.18	0.46	53	26	0.18	0.46	53	26
95	0.44	1.14	142	57	0.38	0.98	117	48	0.38	0.98	117	48
90	0.92	2.38	427	125	0.73	1.90	322	99	0.69	1.79	261	85
85	1.71	4.43	1122	230	1.22	3.16	616	141	1.18	3.07	564	124
80	3.19	8.27	2682	297	2.61	6.77	1855	190	2.84	7.37	2079	188

TABLE 5-4
NOISE IMPACT SUMMARY - E.150.3000 AIRPLANE
WASHINGTON NATIONAL - RUNWAY 36*

EPNL Contour	STANDARD PROCEDURE			LOW IMPACT-PROCEDURE			MINIMUM-IMPACT PROCEDURE		
	Sq.Mi.	Sq.Km.	Population Affected	Sq.Mi.	Sq.Km.	Population Affected	Sq.Mi.	Sq.Km.	Population Affected
100	0.18	0.45	0	0.18	0.46	0	0.18	0.46	0
95	0.44	1.14	0	0.38	0.98	0	0.38	0.98	0
90	0.92	2.38	0	0.73	1.90	0	0.75	1.95	0
85	1.71	4.43	0	1.22	3.16	0	1.39	3.61	0
80	3.19	8.27	649	2.61	6.77	3116	2.42	6.26	0

* NOTE: Population affected and/or annoyed is zero for all three above flight procedures when operating from Runway 18.

TABLE 5-5
NOISE IMPACT SUMMARY - E.150.3000 AIRPLANE
ORANGE COUNTY AIRPORT - RUNWAY 19R

EPNL Contour	STANDARD PROCEDURE				LOW IMPACT-PROCEDURE				MINIMUM-IMPACT PROCEDURE			
	Contour Area		Population		Contour Area		Population		Contour Area		Population	
	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed
100	0.18	0.45	5	3	0.18	0.46	5	3	0.18	0.46	5	3
95	0.44	1.14	131	44	0.38	0.98	143	48	0.38	0.98	143	48
90	0.92	2.38	769	201	0.73	1.90	582	158	0.70	1.81	383	109
85	1.71	4.43	1808	354	1.22	3.16	1169	249	1.22	3.16	1126	214
80	3.19	8.27	4882	468	2.61	6.77	3857	324	2.89	7.49	3067	282

NOISE IMPACT SUMMARY - E.150.3000 AIRPLANE
MIDWAY AIRPORT - RUNWAY 22L

EPNL Contour	STANDARD PROCEDURE				LOW-IMPACT PROCEDURE				MINIMUM-IMPACT PROCEDURE			
	Contour Area		Population		Contour Area		Population		Contour Area		Population	
	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed
100	0.18	0.45	94	39	0.18	0.46	0	0	0.18	0.46	0	0
95	0.44	1.14	1343	455	0.38	0.98	952	329	0.37	0.97	814	280
90	0.92	2.38	4005	1119	0.73	1.90	2212	666	0.62	1.62	1800	543
85	1.71	4.43	7187	1595	1.22	3.16	4466	1000	1.35	3.49	3778	855
80	3.19	8.27	11960	1819	2.61	6.77	8018	1117	3.21	8.32	6895	997

TABLE 5-7
NOISE IMPACT SUMMARY - E.150.3000 AIRPLANE
MIDWAY AIRPORT - RUNWAY 31L

EPNL Contour	STANDARD PROCEDURE			LOW-IMPACT PROCEDURE			MINIMUM-IMPACT PROCEDURE		
	Contour Area		Population Affected	Contour Area		Population Affected	Contour Area		Population Affected
	Sq.Mi.	Sq.Km.		Sq.Mi.	Sq.Km.		Sq.Mi.	Sq.Km.	
100	0.18	0.45	0	0.18	0.46	101	0.18	0.46	101
95	0.44	1.14	1553	0.38	0.98	997	0.37	0.97	795
90	0.92	2.38	4969	0.73	1.90	3743	0.62	1.62	2427
85	1.71	4.43	8682	1.22	3.16	6395	1.34	3.48	5687
80	3.19	8.27	15559	2.61	6.77	12780	3.19	8.27	9956
			2168			1619			1322
			1909			1388			1142
			1368			995			662
			529			340			275
			0			41			41

TABLE 5-8
NOISE IMPACT SUMMARY - E.150.3000 AIRPLANE
10% OVERSIZED ENGINES
MIDWAY AIRPORT - RUNWAY 22L

EPN1 Contour	STANDARD PROCEDURE			LOW IMPACT-PROCEDURE*			MINIMUM-IMPACT PROCEDURE		
	Contour Area		Population Affected	Contour Area		Population Affected	Contour Area		Population Affected
	Sq.Mi.	Sq.Km.		Sq.Mi.	Sq.Km.		Sq.Mi.	Sq.Km.	
100	0.17	0.44	94	40			0.16	0.41	45
95	0.41	1.05	943	321			0.35	0.91	457
90	0.85	2.21	3760	1032			0.59	1.52	1465
85	1.60	4.13	7423	1573			1.26	3.26	3816
80	2.95	7.63	12282	1776			2.99	7.75	6940

*NOTE: Low Impact flight procedure developed for basic E.150.3000 airplane also is applicable to oversized engine airplane. Low impact contour unnecessary for oversized engine case.

TABLE 5-9
NOISE IMPACT SUMMARY - E.150.3000 AIRPLANE
10% OVERSIZED ENGINES
MIDWAY AIRPORT - RUNWAY 31L

EPNL Contour	STANDARD PROCEDURE			LOW-IMPACT PROCEDURE*			MINIMUM-IMPACT PROCEDURE							
	Contour Area		Population	Contour Area		Population	Contour Area		Population					
	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed		
100	0.17	0.44	0	0	<div></div>						0.16	0.41	0	0
95	0.41	1.05	1210	418							0.35	0.91	582	198
90	0.85	2.21	4338	1187							0.59	1.52	2187	568
85	1.60	4.13	9002	1866							1.26	3.27	5688	1042
80	2.95	7.63	14258	2032							2.97	7.68	10245	1236

*NOTE: Low Impact flight procedure developed for basic E.150.3000 airplane also is applicable to oversized engine airplane. Low impact contour unnecessary for oversized engine case.

TABLE 5-10

NOISE IMPACT SUMMARY - M.150.4000 AIRPLANE
HANSCOM FIELD - RUNWAY 5

EPNL Contour	STANDARD PROCEDURES				LOW IMPACT-PROCEDURE				MINIMUM-IMPACT PROCEDURE*			
	Contour Area		Population		Contour Area		Population		Contour Area		Population	
	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed
100	0.26	0.67	80	40	0.28	0.73	90	45	0.28	0.73	90	45
95	0.52	1.35	199	81	0.50	1.30	185	77	0.50	1.30	185	77
90	1.04	2.71	636	187	0.82	2.13	303	107	0.82	2.13	303	107
85	1.83	4.73	1372	298	1.45	3.75	857	186	1.45	3.75	857	186
80	3.29	8.52	2836	361	2.77	7.17	2136	243	2.77	7.17	2136	243

*NOTE: Low impact procedure also is the minimum impact procedure for this airport and runway combination.

TABLE 5-11

NOISE IMPACT SUMMARY - M.150.4000 AIRPLANE
WASHINGTON NATIONAL - RUNWAY 36*

EPNL Contour	STANDARD PROCEDURE			LOW-IMPACT PROCEDURE			MINIMUM-IMPACT PROCEDURE		
	Contour Area		Population Affected	Contour Area		Population Affected	Contour Area		Population Affected
	Sq.Mi.	Sq.Km.		Sq.Mi.	Sq.Km.		Sq.Mi.	Sq.Km.	
100	0.26	0.67	0	0.28	0.73	0	0.28	0.73	0
95	0.52	1.35	0	0.50	1.30	0	0.51	1.33	0
90	1.04	2.71	0	0.82	2.13	0	1.01	2.60	0
85	1.83	4.73	0	1.45	3.75	0	1.63	4.22	0
80	3.29	8.52	293	2.77	7.17	706	2.67	6.92	0
			3			12			0

*NOTE: Population affected and/or annoyed is zero for all three above flight procedures when operating from Runway 18.

TABLE 5-12
NOISE IMPACT SUMMARY - M.150.4000 AIRPLANE
ORANGE COUNTY AIRPORT - RUNWAY 19R

EPNL Contour	STANDARD PROCEDURE			LOW-IMPACT PROCEDURE			MINIMUM-IMPACT PROCEDURE		
	Contour Area		Population Affected	Contour Area		Population Affected	Contour Area		Population Affected
	Sq.Mi.	Sq.Km.		Sq.Mi.	Sq.Km.		Sq.Mi.	Sq.Km.	
100	0.26	0.67	7	0.28	0.73	4	0.27	0.69	39
95	0.52	1.35	392	0.50	1.30	136	0.43	1.12	139
90	1.04	2.71	1192	0.82	2.13	336	0.82	2.11	713
85	1.83	4.73	2627	1.45	3.75	548	1.51	3.90	1606
80	3.29	8.52	5349	2.77	7.17	655	2.84	7.37	2516
									364

TABLE 5-13

NOISE IMPACT SUMMARY - M.150.4000 AIRPLANE
MIDWAY AIRPORT - RUNWAY 22L

EPNL Contour	STANDARD PROCEDURE				LOW IMPACT-PROCEDURE				MINIMUM-IMPACT PROCEDURE			
	Contour Area		Population		Contour Area		Population		Contour Area		Population	
	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed
100	0.26	0.67	263	108	0.28	0.73	538	277	0.26	0.68	400	168
95	0.52	1.35	1703	616	0.50	1.30	1608	612	0.42	1.09	1196	442
90	1.04	2.71	3034	962	0.82	2.13	2681	896	0.82	2.14	2406	753
85	1.83	4.73	6496	1478	1.45	3.75	4862	1218	1.54	3.98	4317	1040
80	3.29	8.52	11352	1686	2.77	7.17	9008	1354	2.89	7.50	8247	1178

TABLE 5-14

NOISE IMPACT SUMMARY - M.150.4000 AIRPLANE
MIDWAY AIRPORT - RUNWAY 31L

EPNL Contour	STANDARD PROCEDURE				LOW IMPACT-PROCEDURE				MINIMUM-IMPACT PROCEDURE			
	Contour Area		Population		Contour Area		Population		Contour Area		Population	
	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed	Sq.Mi.	Sq.Km.	Affected	Annoyed
100	0.26	0.67	202	84	0.28	0.73	405	172	0.26	0.68	202	87
95	0.52	1.35	1653	587	0.50	1.30	1451	540	0.42	1.09	844	314
90	1.04	2.71	5307	1496	0.82	2.13	3609	1069	0.82	2.12	3204	899
85	1.83	4.73	8973	2004	1.45	3.75	6458	1490	1.54	3.98	6136	1328
80	3.29	8.52	14413	2253	2.77	7.17	12482	1764	2.89	7.50	10554	1549

Tables 5-15 through 5-17 provide an overall community noise evaluation summary for the E-150-3000, the E-150-3000 with 10 percent oversized engines, and the M-150-4000 airplanes. The criteria for the evaluation was the total number of persons highly annoyed within the single-event 80 EPNdB noise footprint. The evaluation showed that an average reduction of approximately 40 percent in the number of persons highly annoyed could be achieved by varying flight operational procedures.

Approximately two-thirds of the noise reduction was achieved through a parametric analysis of the various techniques which assumed a uniform population distribution. The remaining third was achieved by tailoring the flight techniques and aircraft flight paths to a specific airport.

The study also investigated the amount of community noise reduction achievable by the E-150-3000 airplane with 10 percent oversized engines. This evaluation was conducted at Chicago Midway, which has the highest population concentration of the four study airports. The results of this evaluation are summarized in Table 5-16. The oversized-engine aircraft provided an average 8 percent reduction in number of persons highly annoyed compared to the basic E-150-3000 airplane.

It should be noted that the two aircraft designs, the E-150-3000 and the M-150-4000, are not directly comparable since they have different takeoff noise levels and field lengths. The study did demonstrate that the use of flight operational procedures to minimize noise impact was equally applicable to each aircraft type; however, the operational procedures varied slightly due to differences in the aircraft acoustic and performance characteristics.

TABLE 5-15 NOISE REDUCTION SUMMARY - E-150-3000 AIRPLANE

AIRPORT	NUMBER OF PERSONS HIGHLY ANNOYED				
	Standard Procedure	Low Impact Procedure	Reduction From Std.	Min. Impact Procedure	Reduction From Std.
BED - HANSKOM FIELD Runway 5	297	190	36%	188	37%
DCA - WASHINGTON NAT'L.					
Runway 36	9	30*	(333%)*	0	100%
Runway 18	0	0	-	0	-
SNA - ORANGE COUNTY Runway 19R	468	324	31%	282	40%
MDW - CHICAGO MIDWAY					
Runway 22L	1819	1117	39%	997	45%
Runway 31L	2168	1619	25%	1322	39%

* The increase from the standard procedure results from a lower power cutback height which extends the 80 and 85 EPNdB contours over highly population areas.

TABLE 5-16 NOISE REDUCTION COMPARISON

MIDWAY AIRPORT	NUMBER OF PERSONS HIGHLY ANNOYED		
	E-150-3000	10% Oversized Engines	Impact Reduction
<u>MDW - RUNWAY 22L</u>			
Standard Procedure	1819	1776	2.4%
Minimum Impact Procedure	997	903	9.1%
<u>MDW - RUNWAY 31L</u>			
Standard Procedure	2168	2032	6.3%
Minimum Impact Procedure	1322	1236	6.5%

TABLE 5-17
NOISE REDUCTION SUMMARY
M-150-4000 AIRPLANE

AIRPORT	NUMBER OF PERSONS HIGHLY ANNOYED				
	Standard Procedure	Low Impact Procedure	Reduction From Std.	Min. Impact Procedure	Reduction From Std.
BED - HANSCOM FIELD Runway 5	361	243	33%	243	33%
DCA - WASHINGTON NAT'L Runway 36 Runway 18	3 0	12* 0	(400%)* -	0 0	100% -
SNA - ORANGE COUNTY Runway 19R	655	402	39%	364	44%
MDW - CHICAGO MIDWAY Runway 22L Runway 31L	1686 2253	1354 17	20% 22%	1178 1549	30% 31%

* The increase from the standard procedure results from a lower power cutback height which extends the 80 and 85 EPNdB contours over highly populated areas.

6.0 CONCLUSIONS AND RECOMMENDATIONS

It has been shown that aircraft operational techniques can significantly reduce airport community noise. The aircraft studied were designed for field lengths of 3000 feet (914 m) and 4000 feet (1200 m) but the methodologies described herein are applicable to all fixed-wing aircraft. The following are conclusions drawn from this study:

Conclusions:

- (1) Over the range considered, some DOC decrease can be obtained at the expense of increased noise level by using engines with a higher fan pressure ratio.
- (2) Acoustical treatment of engine inlet and exhaust ducts, without an increase in dimensions, provides some reduction in noise with little or no increase in DOC.
- (3) A variable-pitch engine with a fan pressure ratio of 1.32 results in an aircraft with a lower TOGW than one with a 1.57 FPR fixed-pitch fan. A 1.32 FPR engine results in a higher DOC because of the slower cruise speed resulting from its lower cruise thrust. Higher fuel prices will decrease the slight DOC advantage of the 1.57 FPR engine. Increasing the fan pressure ratio of a variable-pitch fan while maintaining the capability of operating in the reverse mode will increase cruise thrust. This may reduce operating costs by improved productivity resulting from higher cruise speeds.
- (4) For a MF installation, the bypass ratio of the engine can be controlled so that the primary jet noise will have little effect on the total propulsion system noise level.

- (5) For a field length of 3000 feet (914 m) there is very little difference between a two- and four-engine MF aircraft configuration in terms of direct operating cost. Higher fuel prices will tend to favor the four-engine configuration due to its lower total installed thrust when sized by field length performance.
- (6) The trade study for the E-150-3000 aircraft with 1.25 FPR engines showed that there was very little difference in DOC between an optimum wing geometry and that used in the STOL Systems Study. Changing to an optimum wing geometry (primarily a reduction in wing sweep) would result in approximately a 1 percent reduction in DOC. The insensitivity to wing geometry is due in part to the aircraft sizing philosophy: the engine is selected for a field length and sideline noise requirement rather than a cruise speed requirement.
- (7) The use of engines larger than required to meet field length requirements for an E-150-3000 type aircraft can result in a reduction in community noise impact due to the higher climb gradients and lower allowable takeoff flap angles. There is essentially no increase in DOC for engine over-sizing of less than 10 percent, but there is a fuel consumption penalty. Desirable engine size increases would probably be less than 10 percent. It appears that a similar result would be found for mechanical-flap aircraft.
- (8) For both the EBF and MF aircraft, a decelerating approach procedure produced the smallest noise impact for all of the approach techniques examined. Two-segment approaches and turning approach paths do not provide any gains for low noise aircraft since the 80 EPNdB noise level, the lower limit of the selected annoyance criteria, corresponds to an

aircraft height of approximately 500 feet, a height by which all configuration or path changes should be complete. The lower the aircraft noise level, the less the potential gains on the landing approach due to operational techniques.

- (9) Significant reductions in airport community noise impact were achieved by using results of parametric studies of landing and takeoff flight operational techniques for a specific aircraft design.
- (10) An additional reduction in community noise impact was achieved by tailoring the flight techniques to produce minimum impact at a specific airport and runway combination.
- (11) A reduction in people highly annoyed of approximately 8 percent was achieved by the E-150-3000 with 10 percent oversized engines relative to the basic E-150-3000 airplane at the one airport examined.
- (12) In general, the number of people exposed and/or annoyed by the 80 and 85 EPNdB footprints exceeded by a factor of two the number similarly affected by the 90, 95 and 100 footprints. This points out the necessity of investigating low noise levels in community aircraft noise impact evaluations.
- (13) For the quiet short-haul aircraft examined, takeoff operational techniques offered more potential than landing operational techniques for reducing community noise impact.
- (14) The evaluation procedures and methodology developed in this study provide a useful tool for determining aircraft noise impact upon an airport community.

Recommendations:

- (1) In the MF acoustic trade study, the nacelles were designed for aerodynamic efficiency and the available duct area was acoustically treated for noise suppression. It is recommended, therefore, that the MF acoustic trade study be extended to determine the potential noise reduction that can be achieved by lengthening of the duct and adding more acoustical treatment.
- (2) A study using the methods described in this report should be conducted on current CTOL aircraft. Such an evaluation may provide significant noise reduction potential for existing aircraft.
- (3) Installation of oversized engines should be given consideration in future STOL aircraft designs where noise is a major consideration.
- (4) Investigation of low levels of noise should be included in future STOL short-haul aircraft community noise evaluations due to the relatively high percentage of the population exposed to the lower noise levels.
- (5) The study showed that approximately three times the number of persons were impacted by the 80 EPNdB noise footprint at Chicago Midway compared to the Orange County Airport for a comparable aircraft type. Noise complaint records, however, indicate that far more persons are highly annoyed at Orange County than at Midway (Reference 1). Additional research and development should be conducted to determine relative weighting factors for all elements affecting annoyance. The assumptions and methodology used as a basis for acoustic evaluations need to be studied in more detail. Some areas which warrant further study are as follows:

- a) Addition of source noise levels on a PNL or EPNL basis does not account for the spectral or directional characteristics of the source noise.
 - b) EPNL vs distance maps are based on steady state, level flyovers and are not necessarily representative of takeoff and landing flight procedures.
 - c) Ground attenuation and fuselage shielding as defined by SAE ARP 1114 does not account for the spectral characteristics of the noise or the aircraft structural configuration.
 - d) A standard methodology for generating aircraft noise contours should be established.
 - e) The relationship of the percent people annoyed as used herein needs further study. It equates 80 EPNdB with zero annoyance, and does not take into account the number of operations, time of day, ambient noise conditions, land use, social class structure, etc.
 - f) Operational techniques for noise reduction should be studied at a greater number of airports.
- (6) Operational techniques can also be used to compare flight procedures on the basis of fuel consumption as well as noise impact. A program is recommended for investigating minimum energy terminal area flight procedures.

7.0 REFERENCES

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